

## **A road traffic noise spectrum calculation method based on the noise spectral characteristics of single vehicles**

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### **ABSTRACT**

Vehicle type and driving speed are important factors affecting the vehicle noise spectrum. Therefore, according to the noise spectrum characteristics of single vehicles, the types of vehicles commonly found on Chinese urban roads are classified and the speed interval is divided. Then, by collecting the noise data of a large number of single vehicles, the noise spectrum characteristics of different types of vehicles at different speed intervals are analyzed. Combined with the vehicle noise emission calculation model, the sound pressure level of the vehicle is calculated, and the noise spectrum of the single vehicle is calculated by the sound pressure level and the noise spectral characteristics of the corresponding vehicle type and speed. Finally, the noise spectrum of all vehicles on the road section is superimposed and time-averaged to calculate the road traffic noise spectrum. This calculation method is applied to the actual scene of an urban road, and the calculated noise spectrum is highly similar to the measured noise spectrum.

**Keywords:** Traffic Noise, Noise Spectrum, Noise Frequency

**I-INCE Classification of Subject Number: 76**

### **1. INTRODUCTION**

With the increasing impact of road traffic noise, traffic noise has become one of the major environmental issues in urban areas, studies show that Long-term exposure to noise can cause problems such as insomnia<sup>[1,2]</sup>, high blood pressure<sup>[3,4]</sup>, and myocardial infarction<sup>[5,6]</sup>, and even affect the learning ability of young children<sup>[7]</sup>.

Most countries have their own traffic noise prediction models. For example, the FHWA model<sup>[8]</sup>, the CoRTN model<sup>[9]</sup>, the RLS90 model<sup>[10]</sup>, the CNOSSOS-EU

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project<sup>[11]</sup>, and so on<sup>[12-18]</sup>. These traffic noise prediction models calculate the equivalent sound pressure level of road traffic noise based on the vehicle type, driving speed, traffic volume and other traffic flow parameters.

Although many scholars and research institutions have done a lot of research work on the prediction of traffic noise, the focus of the research is to calculate the equivalent sound level at the receiving point according to the traffic flow parameters, and rarely involves the calculation of the traffic noise spectrum.

The Federal Highway Administration Traffic Noise Model Technical Manual published in 1998 includes a study on the noise spectrum emissions of a single vehicle. In this study, the vehicle types were classified into passenger cars, medium trucks, heavy trucks, buses and motorcycles, the driving state were divided into full horsepower and cruise horsepower. The noise spectrum curves of the vehicle driving at 10,20,30,40,50,60,70,80 miles/h were plotted. In this study, although the noise spectrum of a single vehicle at different speeds and different road surfaces was compared, but it can not be applied to the calculation of traffic noise spectrum.

Hai Yen Thi Phan<sup>[19]</sup> conducted a 24-hour noise monitoring experiment on 8 road sections in three regions, and compared the traffic flow and noise spectrum of the road. Antonio.J<sup>[20]</sup> collected spectral data of road traffic noise, and analyzed the influence of noise in different frequency bands on people's annoyance under different sound pressure levels. Luo Peng<sup>[21]</sup> collected the noise spectrum data of single vehicles of various types of vehicles, and reclassified the models according to the noise spectrum characteristics, the spectral characteristics of different vehicle types are analyzed, in addition, the noise spectrum characteristics of different vehicle speeds in different speed segments are compared.

In summary, in the study of vehicles, the noise spectrum data of a single vehicle is collected, and the noise spectrum is analyzed in combination with the vehicle speed. However, the calculation method and idea of the noise spectrum of the mixed traffic flow are not proposed. In the research of road traffic noise, the traffic noise spectrum data of the road is directly collected, and the characteristics of road traffic noise are analyzed according to the spectrum, but the traffic and speed are not well correlated. There is also no calculation method for the travel noise spectrum.

The research goal of this paper is to propose a calculation method of road traffic noise spectrum, which can calculate the spectrum of road traffic noise while calculating the equivalent sound level of road traffic noise, so as to reflect the characteristics of road traffic noise in a more comprehensive way.

## 2. METHODOLOGY

### 2.1 Classification of Vehicle Types

Vehicles commonly found on Chinese urban roads include passenger cars, light trucks, medium trucks, heavy trucks, engineering trucks, and buses. Some samples of the one-third octave-band spectra of these vehicles were collected, the amount of sample data is shown in Table 1. In the collected data samples, the speed range of the vehicles is [40,50]km/h, since the speed limit of the urban road is 60km/h, the travel speed of most vehicles falls within this speed range.

*Table 1 the sample size of the vehicle noise data collected for vehicle type classification*

Vehicle Type	Passenger cars	Light trucks	Medium trucks	Heavy trucks	Engineering trucks	buses
Sample Size	40	27	20	14	12	21

The difference in speed between different samples will result in a non-uniform sound pressure level, in order to eliminate the difference in spectral sound pressure level caused by the difference in sound pressure level, calculate the percentage of the sound energy in each frequency band of the sample data as a percentage of the total sound energy, it is named as spectral energy contribution rate in this paper, this percentage represents the spectral characteristics of the noise, and it can be calculated by Equation 1.

$$P[k] = \frac{10^{0.1 \cdot L_k}}{10^{0.1 \cdot L}} * 100\%, k = 1, 2, \dots, 32 \quad (1)$$

Where  $P[k]$  is the spectral energy contribution rate at the  $k$ -th center frequency of the one-third octave,  $L_k$  is the sound pressure level at the  $k$ -th center frequency of the one-third octave,  $L$  is the sound pressure level of the vehicle,  $k$  represents different center frequency of the one-third octave.

For the same type of vehicle, the average of the spectral energy contribution rates of different samples is taken as the representative value of the spectral energy contribution rate of such models. Compare the spectral energy contribution rate curves of different types of vehicles, as shown in the following figure.

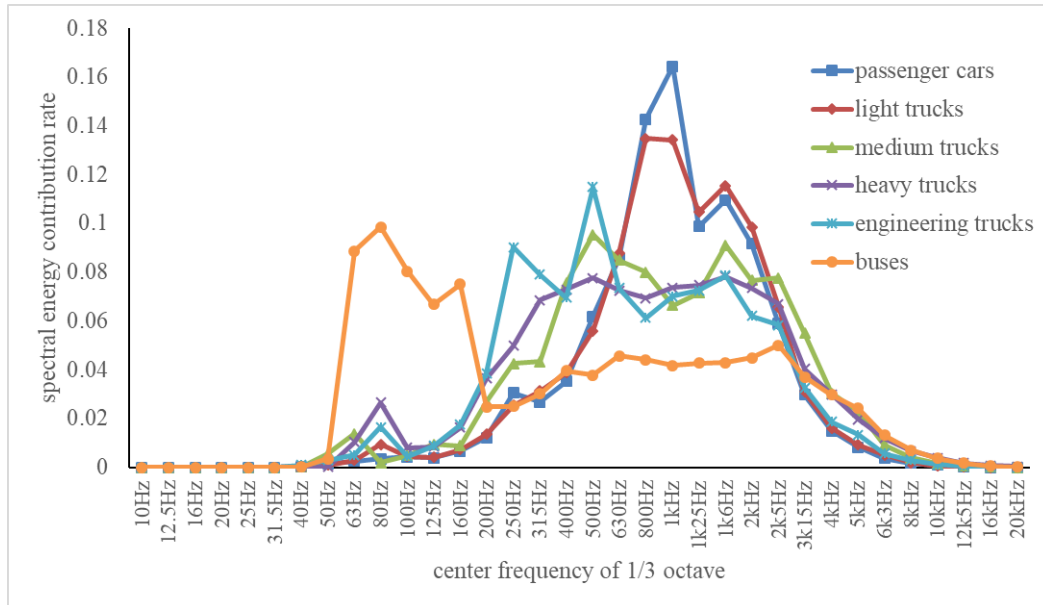


Figure 1 the comparison of the spectral energy contribution rate of different types of vehicles

Obviously, the spectral energy contribution rate curves of passenger cars and light trucks are almost the same, the curve of medium trucks is more biased toward the high frequency than the curves of heavy trucks and engineering trucks, while the curve of buses is significantly different from the other curves. Therefore, the vehicle type is reclassified into four categories as shown in table 2. Noise data is collected according to the vehicle type classification and the sample sizes are also shown in table 2.

Table 2 reclassification of vehicle type and the sample size of the noise data collected

Vehicle Type	Light vehicles		Medium vehicles	Heavy vehicles		buses
Vehicle Type	Passenger cars	Light trucks	Medium trucks	Heavy trucks	Engineering trucks	buses
Sample size	1049		210	261		88

## 2.2 Division of Speed Intervals

The reason why the speed intervals are divided instead of considering the noise spectrum for each speed separately is that the noise spectrum curves of adjacent speeds are very close, and merging adjacent speeds can reduce the amount of calculation and the data acquisition amount of a single speed.

In general, the smaller the speed interval is divided, the more accurate the noise spectral energy contribution rate is, and the more data needs to be collected. Due to the large sample size of the collected data, the speed interval is divided by a step size of 2km/h in this paper.

## 2.3 Calculation of traffic noise spectrum

After the reclassification of vehicle types, noise data collection, and speed interval division, we obtained the noise spectral energy contribution rates of different vehicle types in different speed intervals. The noise spectral energy contribution rate of vehicle type  $i$  in the speed interval  $j$  is recorded by an array  $P_{i,j}[]$ .

To calculate the traffic noise spectrum of a road segment, the traffic flow data should be collected first, including the vehicle type, driving speed, traffic volume, etc. Then, classify the vehicles on the road according to the vehicle type and driving speed, so that each vehicle corresponds to an array  $P_{i,j}[]$ .

The vehicle noise emission model is used to calculate the equivalent sound pressure level of each vehicle to the receiving point, converting the equivalent sound pressure level into sound energy, and then combining the noise spectrum energy contribution rate of the corresponding model and speed, the noise spectrum of the single vehicle to the receiving point can be obtained, shown as Equation 2.

$$S_{i,j}[] = 10\lg(E_{i,j} * P_{i,j}[]) = 10\lg(10^{0.1 * L_{i,j}} * P_{i,j}[]) \quad (2)$$

Where,  $S_{i,j}[]$  is the noise spectrum of vehicle type  $i$  in the speed interval  $j$ ,  $E_{i,j}$  is the sound energy of vehicle type  $i$  in the speed interval  $j$ ,  $L_{i,j}$  is the equivalent sound pressure level of vehicle type  $i$  in the speed interval  $j$ , which can be calculated by the vehicle noise emission model.

Finally, by superimposing the noise spectrum of all vehicles, the traffic noise spectrum of the road section can be calculated, shown in Equation 3.

$$S[] = \frac{1}{T} 10\lg \sum_{i=1}^n \sum_{j=1}^m \sum_{k=1}^{N_{i,j}} S_{i,j}[] \quad (3)$$

Where,  $S[]$  is the noise spectrum of the road traffic noise,  $T$  is the length of experiment, usually 1 hour,  $n$  is the number of vehicle types,  $m$  is the number of speed intervals, and  $N_{i,j}$  is the traffic volume of the  $i$ -th type vehicle in the  $j$ -th speed interval.

## 3. CASE STUDY

### 3.1 Experimental Scene

A four-lane asphalt road without a central green belt was selected as an experimental scene, the lane width is 3.5m, shown as figure 2.



Figure 2 the experimental scene

A one-hour measurement experiment was conducted, the noise spectrum, traffic volume, driving speed of each type of vehicle are collected. The sound level meter is placed 20cm from the edge of the road and is 1.2m above the ground. The traffic volume of each type of vehicle passing by during the experiment is shown in table 3.

Table 3 the traffic volume of each type of vehicle

	Light vehicles	Medium vehicles	Heavy vehicles	buses
East to West	427	33	21	6
West to East	343	38	18	7

### 3.2 Noise Spectrum Calculation

The localization model established by Lin<sup>[22]</sup> was chosen as the vehicle noise emission model in this study, shown in Equation 4.

$$\begin{cases} \text{light vehicles: } L_{ol} = 27.96 + 24.91 \lg V \\ \text{medium vehicles: } L_{om} = 28.36 + 29.73 \lg V \\ \text{heavy vehicles: } L_{oh} = 31.77 + 29.70 \lg V \end{cases} \quad (4)$$

Equation 4 calculates the sound pressure level of the vehicle when it is 7.5m away from the receiving point, by integrating the time, the equivalent sound pressure level of the receiving point emitted by the vehicle can be calculated, shown as Equation 5.

$$L_{eqo} = 10 \lg \frac{1}{T} \int 10^{0.1L_v} dt = L_o + 10 \lg \frac{\pi r_o}{TV} \quad (5)$$

Divide the road traffic flow into multiple traffic flows by vehicle type and driving speed, calculate the equivalent sound pressure level of each traffic flow to the receiving point, and consider the distance attenuation of the sound by the equivalent lane, shown as Equation 6.

$$L_{eqij} = 10 \lg \sum_{m=1}^{N_{i,j}} 10^{0.1L_{eqoij}} + 10 \lg \frac{r_o}{r} = L_{oij} + 10 \lg \frac{N_{i,j}}{TV_j} + 10 \lg \pi r_o + 10 \lg \frac{r_o}{r} \quad (6)$$

Where,  $L_{eqij}$  is the equivalent sound pressure level of the traffic flow consist of i-th type of vehicle that driving in the j-th speed interval,  $L_{oij}$  is the sound pressure level of the i-

th type of vehicle driving in the j-th speed interval,  $r_0 = 7.5m$  is the reference distance of the noise emission model, and  $r$  is the distance from the receiving point to the equivalent lane, it is the geometric mean of the distance from the receiving point to the nearest lane centerline and the farthest lane centreline,  $r = 5m$  in this case.

The equivalent sound pressure level and the noise spectrum of the road traffic noise can be calculated by Equation 2, Equation 3, and Equation 6. The calculated equivalent sound pressure level is 73dB, while the measured value is 74.3dB. The noise spectrum is shown in figure 3.

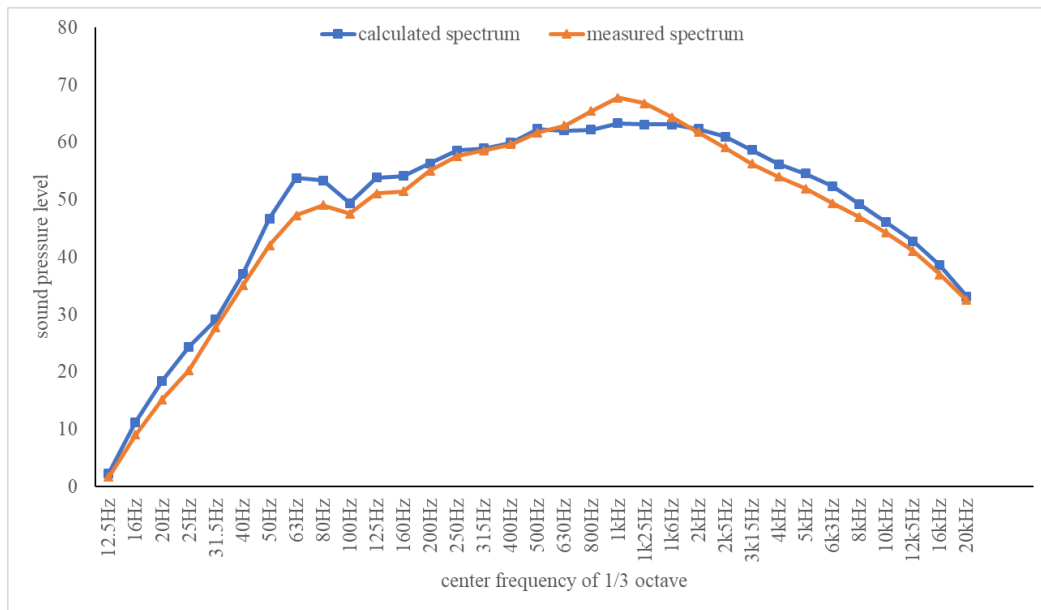


Figure 3 the noise spectrum of the calculated result and the measured value

The standard deviation of the spectral sound pressure level between the calculated result and the measured value is 2.24.

The spectral energy contribution rate curve of the calculated result and the measured value is shown in figure 4. The Euclidean distance between spectral energy contributions is 0.16.

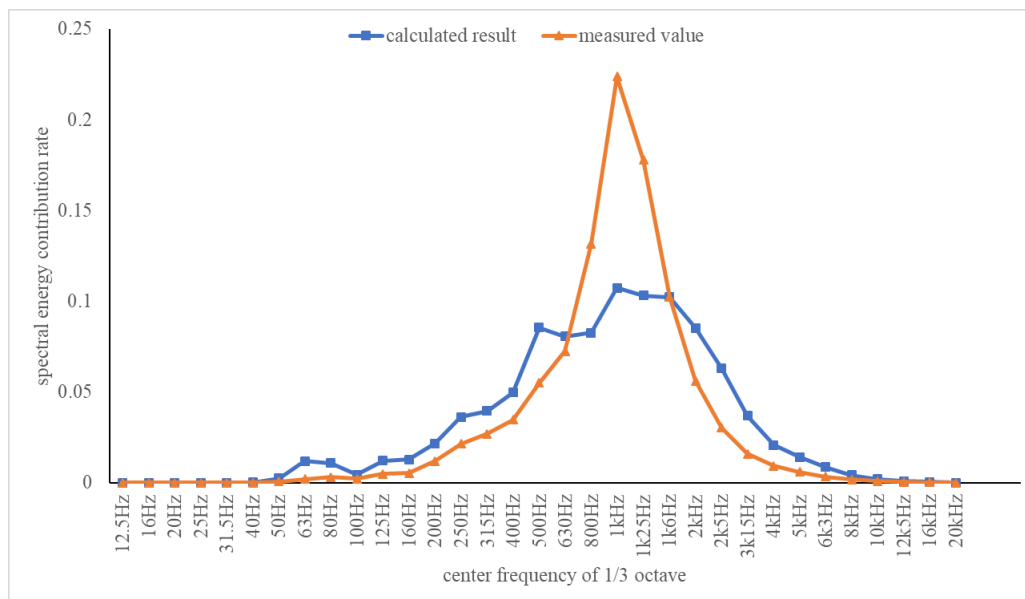


Figure 4 the spectral energy contribution rate of the calculated result and the measured value

It can be seen in figure 3 and figure 4 that the curves of the calculation result and the measured value are very close, which means that the calculation result is acceptable.

#### 4. CONCLUSIONS

This study collects a large number of vehicle noise spectrum data, analyzes the spectral characteristics of different types of vehicles at different driving speeds, and reclassifies vehicle types and divides speed intervals according to spectral characteristics.

Based on vehicle noise emission model and spectrum characteristics, this study proposes a method for calculating the road traffic noise spectrum. Through the test of the actual scene, it is found that the calculated noise spectrum curve is very close to the measured spectrum curve, and the accuracy of the calculation result is high. The method can be applied to the calculation of the actual road traffic noise spectrum.

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