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THE STUDY OF VERTICAL DISTRIBUTION OF URBAN ROAD TRAFFIC NOISE

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Abstract

Currently, traffic noise of urban road has serious effect on residents living beside the road. Because of the buildings beside urban roads, the vertical distribution of noise is complex. Sometimes residents living on high floor are affected seriously. For better control of traffic noise, it has real significance to study the vertical distribution of traffic noise. Through noises monitoring of road traffic in Beijing, we analyse and study the vertical distribution of high-rise buildings beside urban roads, and give the characteristics of road traffic noise attenuation with the vertical direction.

1. INTRODUCTION

At present, along with the rapid development of road construction and the increase of vehicles in many cities in China, road traffic noise pollution is getting more serious, especially for the residents living beside urban roads. The vertical distribution characteristics of noise beside urban roads are complex because of the effect of other buildings, green belts and barriers. Sometimes traffic noise makes more serious impact on the residents living on higher floor than on lower floor. In order to reduce the impact of traffic noise on residents living beside roads, it is necessary to study the vertical distribution characteristics of road traffic noise. Meanwhile it is significant for urban planning and architecture design. In the paper, the noise data is acquired at vertical direction outside the buildings of various roads in Beijing. The vertical distribution characteristics of traffic noise about roadside high-rise buildings are studied and analyzed.

2. TRAFFIC NOISE PROPAGATION ANALYSIS

During sound propagation, the area of wave spreads with the distance from sound source. So sound energy spreads from distributing in smaller area to a larger area gradually, and sound energy density decreases. The phenomenon of sound intensity weakening with the area of wave spreading is known as geometrical divergence attenuation.

Because traffic flow of urban road is large generally, an urban road can be regarded as a rectangular plane sound source approximately. Assuming that two sides of the rectangle as ‘a’ (road width) and ‘b’ (road length) separately, usually a<b. Every point of the surface of a plane

sound source vibrates in different amplitude and phase, i.e. the sound waves which the sound source radiates are irrelevant. Suppose that the surface of a plane sound source is divided into infinite surfaces ‘ds’. It may be regarded that every point vibrates equably on each ‘ds’. So we can regard the surface ‘ds’ as a point sound source[1].

Suppose the vibration law of a point sound source at (x,y,z) is the following formula.

$$u = u_A(x,y,z)e^{j[\omega t-\alpha(x,y,z)]} \tag{1}$$

Where

$u_A(x,y,z)$ is the vibration velocity of the ‘ds’.

$\alpha_A(x,y,z)$ is the initial phase of the ‘ds’.

Suppose intensity of the point sound source is

$$dQ_0 = u_A(x,y,z)dS \tag{2}$$

When the ‘ds’ vibrates, the sound pressure it produced is

$$dp = j\frac{k\rho_0 c_0}{4\pi h(x,y,z)} dQ_0 e^{j[\omega t-kr(x,y,z)-\alpha(x,y,z)]} \tag{3}$$

Where

$r(x,y,z)$ is the distance from the source to receiver, in metres.

Every ‘ds’ all contributes to sound field, so the total sound pressure can be calculated by interpreting the contributions. Considering the surface radiates in the half free field, the total sound pressure is

$$p = \iint_S j\frac{k\rho_0 c_0}{2\pi h(x,y,z)} u_A(x,y,z)e^{j[\omega t-kr(x,y,z)-\alpha(x,y,z)]}dS \tag{4}$$

According to the formula, the sound pressure level dropping with distance should take into account three cases[2].

When r < $\frac{a}{\pi}$, the sound pressure almost don’t drop, i.e. the source radiates plane wave near the plane sound source, the sound pressure level will not drop with the distance to the source.

When $\frac{a}{\pi} \le$ r < $\frac{b}{\pi}$, the sound pressure drops like a line sound source, i.e. far away from the source, the sound pressure level drops by approximately 3dB for a doubling of distance from the source.

When r ≥ $\frac{b}{\pi}$, the sound pressure drops like a point sound source, i.e. far enough away from the source, the sound pressure level drops by approximately 6dB for a doubling of distance from the source.

In Beijing, width of a single lane is approximately 3.75m. For different number of lanes of roads, we can calculate the minimum distance to the source which meets attenuation characteristics of a line source.

Table 1. The minimum distance to the source meeting

attenuation characteristics of a line source

Number of lanes	Distance(m)
2	2.4
4	4.8
6	7.2
8	9.6
10	11.9
12	14.3

According the table, the buildings next to urban roads are approximate in the area meeting attenuation characteristics of a line source. So with the floors' increasing, the distance between receiving points and source points increases, and the sound pressure level drops gradually. But this is not the case in vertical direction, so it's necessary to analyze and study the fact.

3. NOISE DATA ACQUISITION AND ANALYSIS

We select five kinds of ground roads according to the number of lanes. They are two-lane, four-lane, six-lane, ten-lane and twelve-lane roads. For every kind of road, we choose two roads, One road has high-rise buildings on both sides， the other has high-rise buildings on one side. Then we collect noise data of the buildings close to the chosen roads in a vertical direction.

We make data acquisition principle to the comparability of data:

-Road vehicles under normal conditions;

-Measurement points are located one meter away from the buildings;

-Simultaneously monitoring at different height on the same road;

-Sound pressure level is described by 20 minute L_{Aeq}.

The shortest distance between lane and building are showed in table 2~table 6.And sound pressure level (SPL) curves are showed in figure 1~figure 5.

The relationship between floors and height of a building meets the following formula approximately.

$$h = 3(F - 1) + 1.5 \tag{5}$$

Where

h is the height, in meters.

F is the number of floors.

Table 2. The shortest distance between lane and building for two-lane roads

Buildings	Distance(m)
high-rise buildings on both sides of the road	13
high-rise buildings on one side of the road	9

Table 3. The shortest distance between lane and building for four-lane roads

Buildings	Distance(m)
high-rise buildings on both sides of the road	18
high-rise buildings on one side of the road	24

Table 4. The shortest distance between lane and building for six-lane roads

Buildings	Distance(m)
high-rise buildings on both sides of the road	22
high-rise buildings on one side of the road	17

Table 5. The shortest distance between lane and building for ten-lane roads

Buildings	Distance(m)
high-rise buildings on both sides of the road	33
high-rise buildings on one side of the road	13

Note：In table 5, a building of four storeys is in front of measurement points, where buildings are on both sides of the road.

Table 6. The shortest distance between lane and building for twelve-lane roads

Buildings	Distance(m)
high-rise buildings on both sides of the road	29
high-rise buildings on one side of the road	33

Note：In table 6, a building of three storeys is in front of measurement points, where buildings are on both sides of the road.

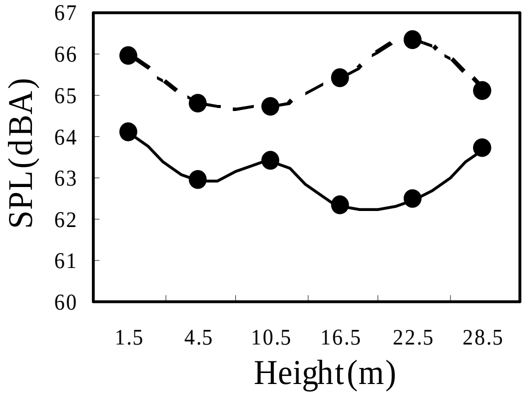

Figure 1.SPL curves in vertical direction for the two-lane roads: high-rise buildings on both sides of the road(——) and high-rise buildings on one side of the road(- - - -)

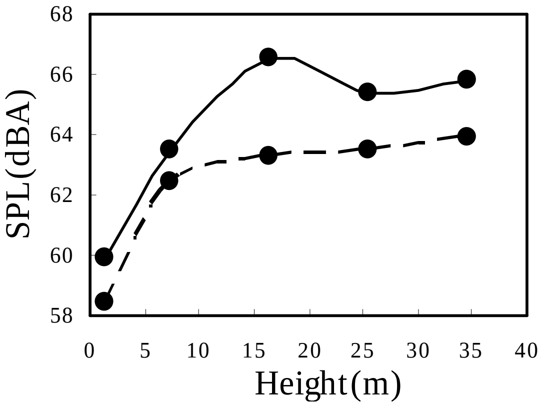

Figure 2.SPL curves in vertical direction for the four-lane roads: high-rise buildings on both sides of the road(———) and high-rise buildings on one side of the road(-----)

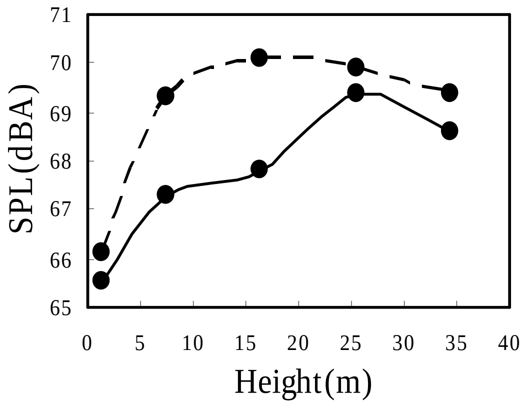

Figure 3.SPL curves in vertical direction for the six-lane roads: high-rise buildings on both sides of the road(———) and high-rise buildings on one side of the road(-----)

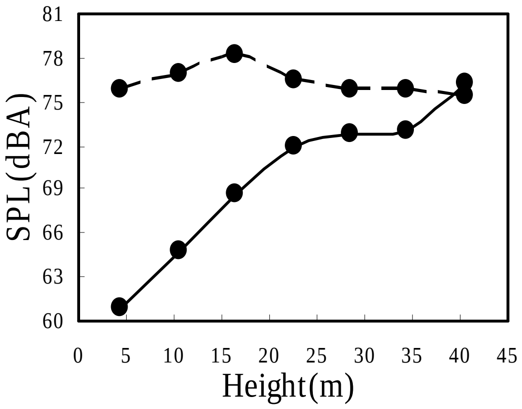

Figure 4.SPL curves in vertical direction for the ten-lane roads: high-rise buildings on both sides of the road(———) and high-rise buildings on one side of the road(-----)

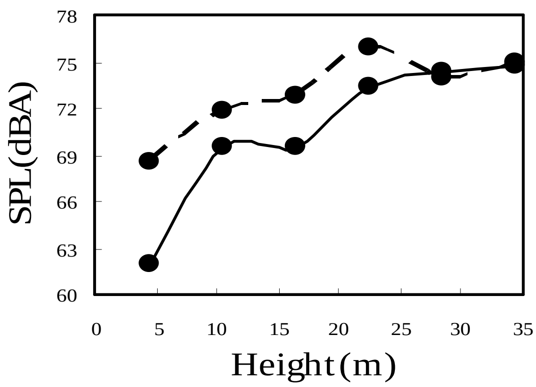

Figure 5.SPL curves in vertical direction for the twelve-lane roads: high-rise buildings on both sides of the road(———) and high-rise buildings on one side of the road(-----)

According to the analysis of the sample data, for the two-lane road, sound pressure level of the first floor is basically the maximum. For the other roads, with the increase of the number of lanes, the maximum sound pressure level may emerge in higher floor. If low-rise buildings are located between high-rise buildings and roads, they have obviously shielding effect on lower floors of high-rise buildings. The sound attenuation law is not obvious，no matter the road has high-rise buildings on both sides or one side.

4. STUDY OF VERTICAL DISTRIBUTION CHARACTERISTICS

During the sound propagation outdoors, a sound attenuation will occur due to ground effect, barrier and so on. For low-rise buildings, it is effective. But the vertical direction of above the

10 meter height, this effect is small. For the multi-lane road, with the increase of the number of lanes, the maximum sound pressure level may emerge in higher floor. It's worth studying.

The reason has been brought forward [3]: on lower floors, traffic noise source can be considered as a line sound source. With the floors increasing, noise source transits from a line sound source to a plane sound source. With the floors increasing again, noise source transits to a line sound source or a point sound source. But from the analysis of traffic noise propagation, we can conclude that the buildings on both sides of urban roads are in the area of a line sound source. So we need to think about whether other shielding causes the change or not.

Generally we pay more attention to shielding effect of barrier beside the road. For multi-lane roads, we neglect the shielding effect that the vehicles near the building take on the vehicles away from the building. According to ISO9613-2[4], the vehicles near the building can be considered as barrier, and reflection of opposite vehicles may be ignored[4]. Because of attenuation caused by vehicles shielding, the height where maximum sound pressure level emerged is out of shielding of the vehicles.

Based on the foregoing analysis, the location where the maximum sound pressure level emerged is relative with the distance between lanes. To make the analysis easier, a line sound source may be simplified to an equivalent lane. The distance between equivalent lane and receiving point is determined by the following formula.

$$D_E = \sqrt{D_N \bullet D_F} \tag{6}$$

Where

D_E is the distance between receiving point and equivalent lane, in metres;
D_N is the distance between receiving point and the nearest equivalent lane, in metres;
D_F is the distance between receiving point and the farthest equivalent lane, in metres.

By making regression analysis of vertical height where the maximum sound pressure level emerged and equivalent distance, we conclude the following regression equations.

$$h_{\max} = 26.9\ln(D_E) - 67.2 \tag{7}$$

Where

$h_{\max}$ is the vertical direction where the maximum sound level emerged, in metres;
D_E is the distance between receiving point and equivalent lane, in metres.

Table 7. Data of regression analysis

D_E (m)	Measured data h_{max}(m)	Computed data h_{max}(m)
50.1	34.5	38.1
45.7	34.5	35.6
47. 6	40.5	36.7
25.1	22.5	19.5
30.6	25.5	24.8
25.3	18.5	19.7
29.8	25.5	24.1

23.7	16.5	18.0
15.6	1.5	6.7
11.5	1.5	-

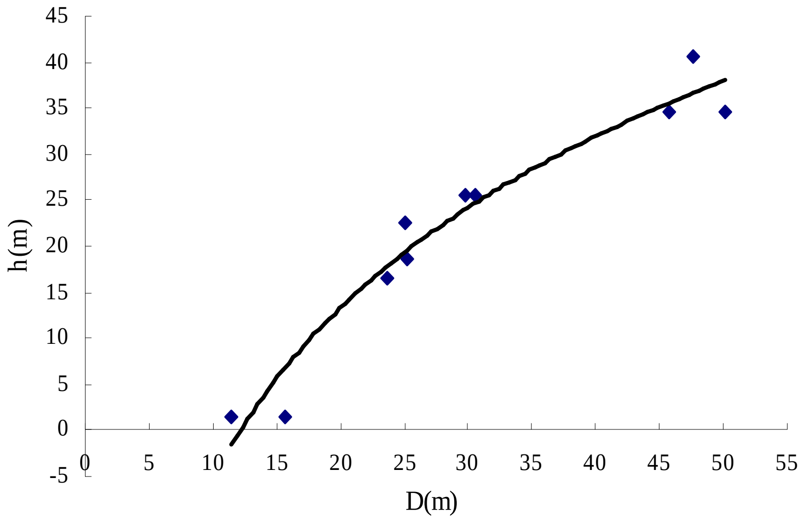

Figure 6. regression curve

From the data calculated by regression equations, it is concluded that the regression curve agreed well with the measured data except for two-lane roads.

According to the sample data, sound pressure level drop gradually above the position of maximum sound pressure level. On the basis of traffic noise propagation analysis, above the position of maximum sound pressure level,the sound attenuation should satisfies attenuation characteristics of a line sound source. Below the position sound attenuation is complex, and we should considered about vehicles shielding, barrier shielding and ground effect.

5. ENDING

The paper studies the vertical distribution characteristics of traffic noise about high-rise buildings that are close to the roads of different width, and acquires a regression equation between the position of the maximum sound pressure level and the equivalent distance of lanes. Besides，the paper makes simple analysis on noise attenuation of above or below the position of the maximum sound pressure level. It is helpful for urban planning and architecture design.

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