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Research

The Contribution of the High-Speed Railway Noise and Its Reduction Approaches

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Abstract: With increasing the speed of the railways give rise to the noise generation and vibration in the environment. When the speed of the HSR increased than 300 km/h, the major noise contribution of the HSR is aerodynamic noise, it becomes leading noise and grow at the rate of sixth to the power of train speed. Subsequently, at higher speeds the contribution of aerodynamic noise will eventually exceeds the power (engine) and rolling noise and finally become the dominant contributor. This paper present, an approach to predict the noise contribution of the high speed railway noise by processing the noise of the railway in the MATLAB R2019b software. The most of the noise of the high speed railway is due to frequency less than 2000 Hz. The peak noise is lies in the frequency range of 400-1200 Hz, which is the noise due to bogie area noise. The soundPlan software is used to predict the effectiveness of the noise barrier. The construction of a 3 m high noise barrier along one side of the railway track resulted in the reduction of overall noise more than 10 dB(A) and even more if the noise barrier are constructed with noise absorbing materials having high density and coefficient of absorption.

Keywords*:* Noise Control; High-Speed Railway Noise; Sound Pressure Level dB(A); and Noise Reduction

1. Introduction

In general, high-speed trains consist of three kinds of acoustic sources [1], namely, traction motor system, rolling wheels and aerodynamic factors. They play different roles at different ranges of train speed. Relevant researches [2] have shown that noise due to traction motor system and rolling wheels vary proportionally to the first and third power of train speed, respectively. However, aerodynamic noise grows at the sixth power of train speed. Consequently, with the continuous increase of train speed, the contribution of aerodynamic noise will eventually exceed that of traction motor system noise and rolling noise and will finally become the dominant factor.

A series of external noise measurements were carried out on board a high-speed train by Bracciali et al. [3] using a specially designed device with microphones in the axle-box of a carriage in proximity to a single wheel.

Barsikow [4] gave the principal results from noise measurements made with microphone arrays of different configurations and arrangements to find out acoustic sources on the Deutsche Bahn AG trains at the speed of from 60 km/h to 280km/h. Kitagawa et al. [5] attempted to validate TWINS model for rail and wheel noise prediction based on comparison with measurements for four different wheel/rail combinations. A field experiment was conducted by De Coensel et al. [6] to study the possible differences between conventional and high-speed trains in perceived noise annoyance. Wakabayashi et al. [7] performed acoustic measurement of Shinkansen high-speed test train (FASTECH360S, Z) to test countermeasures for the reduction of noise of high-speed train such as using low-noise pantograph, sound absorbing panels and pantograph noise insulation plates.

It was investigated by Xiao-Ming Tan et al., [8] that the noise generated by high speed train has a frequency range between 100 and 5000 Hz. The highest noise generated from the bogie area of the high speed train with a frequency range between 400 and 800 Hz. Lee et al., [9] numerically examined the aerodynamic noise generated by different component of the pantograph of high speed train running at 400 km/h such as bottom frame, pan head area, the bulge area between upper and lower arm, and the whole pantograph area are in the frequency ranges 60-400 Hz, 600-800 Hz, 1000-2000 Hz and 2000-5000 Hz respectively. In literature [10][11][12][13][14][15] many different techniques have been used to reduce the noise. The micro-punch can be used to reduce the high frequency noise but it’s not efficient for the lower frequency noise. By using micro-punch, the noise having frequency higher than 1000 Hz noise could be reduced. The construction of a 3 m high noise barrier along one side of the railway track resulted in the reduction of overall noise more than 10 dB(A) and even more if the noise barrier are constructed with noise absorbing materials having high density and coefficient of absorption.

2. Methodology

2.1 MATLAB programming

The noise of the high speed train moving with speed more than 300 km/h is recorded near Beijing, China. The sound was recorded at a horizontal distance of 7.5-15 m from the center-line of track. The noise of the CRH railway was recorded and saved by the Dr. MA Jinsheng while he was at the Beijing Railway Station. A HSR was passing by Beijing railway station and Dr. MA Jinsheng records the Noise of the HSR in the Audio (.wav) form. The audio is used in the programming in the MATLAB R2019b software to measure the SPL. The Programming is shown in the figure 1.

CRH_Noise_SPL_vs_Frequency.m - WordPad

```
source = dsp.AudioFileReader('CRH_Noise_SPL_vs_Frequency.wav');
fs = source.SampleRate;

player = audioDeviceWriter('SampleRate',fs);

SPL = splMeter( ...
    'Bandwidth','1/3 octave', ...
    'SampleRate',fs);
centerFrequencies = getCenterFrequencies(SPL);
%centerFrequencies=(1:40000/30:40000);

scope  = dsp.ArrayPlot(...
    'XDataMode','Custom', ...
    'CustomXData',centerFrequencies, ...
    'XLabel','Octave Band Center Frequencies (Hz)', ...
    'YLabel','Equivalent-Continuous Sound Level (dB)', ...
    'YLimits',[20 90], ...
    'ShowGrid',true, ...
    'Name','Sound Pressure Level Meter');


LeqPrevious = zeros(size(centerFrequencies));
while ~isDone(source)
    x = source();
    player(x);
    [~,Lt] = SPL(x);
```



```
LeqPrevious = zeros(size(centerFrequencies));
while ~isDone(source)
    x = source();
    player(x);
    [~,Lt] = SPL(x);

    for i = 1:size(Lt,1)
        if LeqPrevious ~= Lt(i,:)
            scope(Lt(i,:)')
            LeqPrevious = Lt(i,:);
        end
    end

end

release(source)
release(player)
release(SPL)
release(scope)
```

Figure 1: The programming of the MATLAB to investigate the spectrum of the Noise SPL dB(A) in terms of frequency Hz

2.2 The SoundPlan Software

The numerical measurement of the influence of the high speed railway noise on the environment was investigated with the help of Sound-PLAN software of version 8.2. The layout was established in three categories i.e. residential and commercial area, schools and hospitals, and countryside. The CNR Chinese Railways of Class43 (HST Power Car) was chosen from the system's library that is running approximately at 300 km/h. The layout of the environment is shown in the figure 2 below. The 3d map is shown in the figure 3.

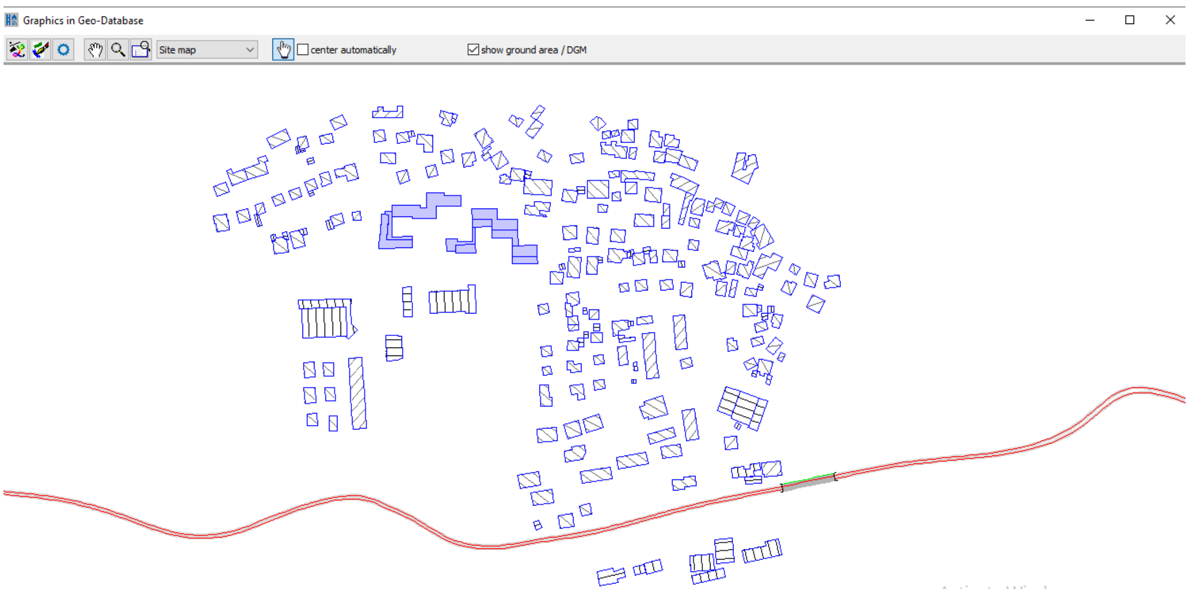

Figure 2: The site map of the environment

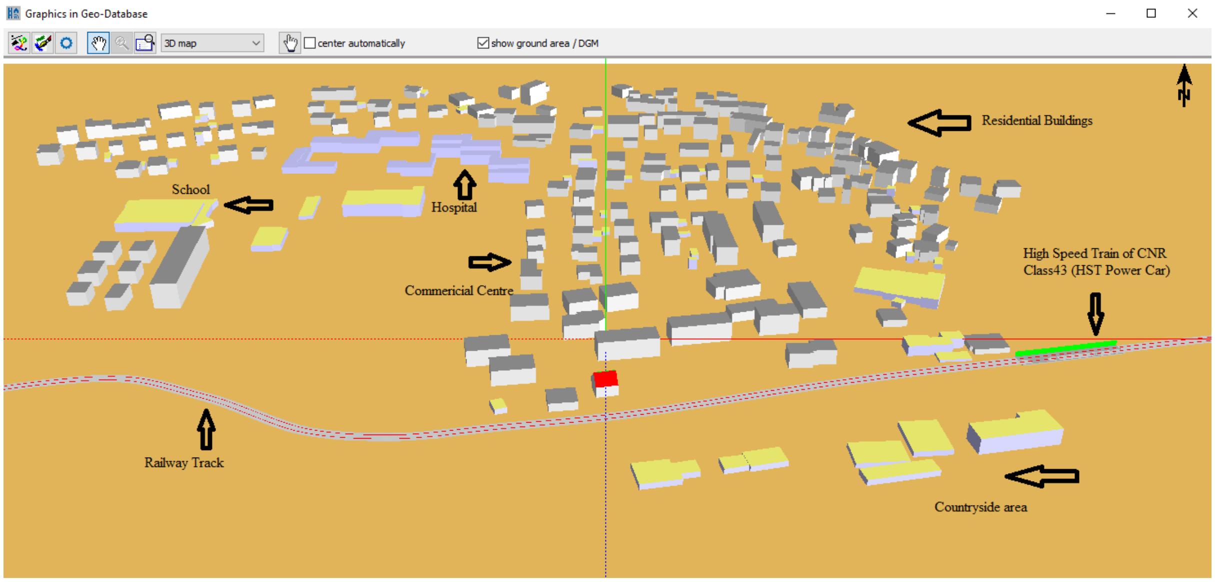

Figure 3: The 3d layout of the environment

A noise barrier along the railway track to reduce the influence of the noise of the high speed railway. This might help in reducing the noise of the HSR at some extent and will be proposed in our study. After applying this noise barrier, we will see how effective way this method is to drop the noise concentration specifically for the residential areas alongside the railway track.

2.3 Impedance Tube

Density of the material has very good effects on the sound absorbing ability of the material. For many materials with increase the density of the material the absorbing coefficient goes on increasing but for some materials show negative effect for some reasons.

Multilayer absorbing materials has been used in many studies to get best absorbing results. With increasing the number of layers the noise absorbing coefficient increases and total noise absorption is the sum up the coefficient of absorption of the all the layers. By maintaining the air gap between the sample (noise absorbing material) and the back rigid layer of the impedance tube increased the sound absorbing ability.

Many synthesis materials used for the application of noise mitigation has some negative aspects because of their toxic behavior and these are sometimes caused health problems for the human beings.

The schematic and photograph of the impedance tube is shown in the figure 4 [16]. It is consists of two microphones as the ASTM standard a horn driver (noise source), sample holder, a system to analyze the noise absorption coefficient as shown in the figure 4.

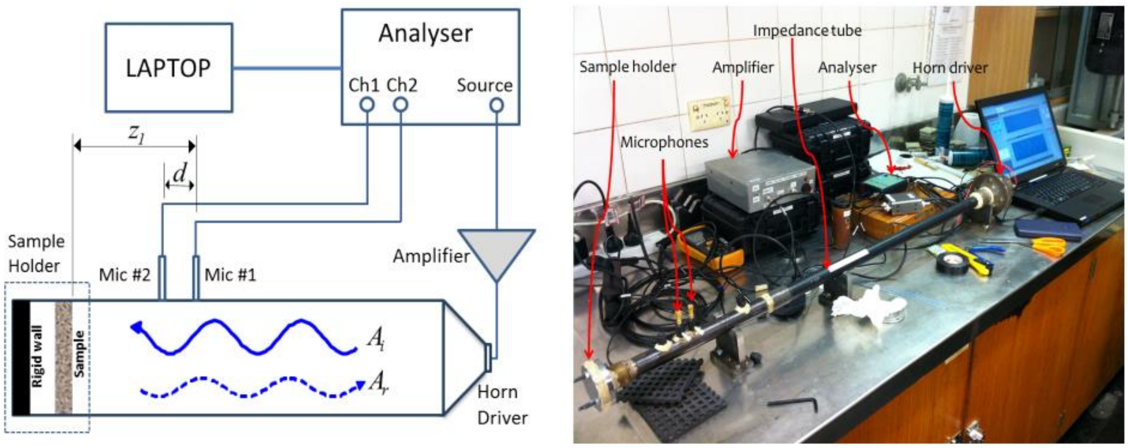

Figure 4: (a) Schematic and (b) photograph of impedance tube and instrumentation used to measure the absorption coefficient of the sample

The most famous research was of Delany and Bazley [17] studied the wave propagation and impedance characteristics of rubbery materials. After [17] the [18] followed similar method to investigate the relationship between impedance and the propagation properties of the foam and multilayer absorbing materials. Miki discusses that at low frequency the surface impedance results negative values then he modified the model described by [84] and get positive values of the impedance in broad frequency range [19]. Also in [20] he argued a more comprehensive method to get impedance values by the terms porosity, tortuosity and the pore diameter.

The absorption coefficient of the material can be calculated by the equations (1-4)

$$\alpha = \frac{Ea}{Ei} \quad (1)$$

$$\alpha = 1 - \frac{Er}{Ei} \quad (2)$$

$$\alpha = 1 - |r|^2 \quad (3)$$

$$\alpha = \frac{I\ Abs}{Ei} \quad (4)$$

Where α = sound absorption coefficient E_I = incident energy, E_r = reflection energy, E_a = absorbed energy, r= incident reflection factor I_{Abs} = Sound intensity absorbed, I_I = Incident sound intensity

The impedance characteristics, the propagation constant and acoustics impedance are can be obtained from the equations [17], [18] and acoustic noise absorption coefficient [21] as equation (5-8).

$$Zm = \rho 0 c 0\{[1 + c1\left(\frac{f\rho o}{\sigma}\right)^{c2}] - i[c3\left(\frac{f\rho o}{\sigma}\right)^{c4}]\} \quad (5)$$

$$\gamma m = k0\{[c5\left(\frac{f\rho o}{\sigma}\right)^{c6}] - i[1 + c7\left(\frac{f\rho o}{\sigma}\right)^{c8}]\} \quad (6)$$

$$\tau \mathrm{m} = Zm \cot \mathrm{h}(cm\ tm) \quad (7)$$

$$\alpha = \frac{4\mathrm{Rr}/\mathrm{q0c0}}{\left(\frac{\mathrm{Rr}}{q0c0}+1\right)^2 + (\mathrm{Xr}/\mathrm{q0c0})^2} \quad (8)$$

3. Results and Discussion

3.1 The SPL Spectrum of the recorded noise of the high speed railway

The spectrum of the noise generated by the high speed train is shown in the figure 5. Figure 5 shows the spectrum of the high speed train noise in frequency domain. In the figure, it is shown that the most of the noise is generated by the sounds, lies in the frequency range of 20-4000 Hz. The maximum noise is produced by the sounds with the frequency less than 2000 Hz. the concentration of the noise in the lower frequency is denser as compared to the high frequency sounds. The noise peak is shown at the frequency range between 500-1200 Hz frequency ranges. From the study of Xiao Ming Tan et al., in [8], the noise produced by the bogie area consists of frequency range of 800-1200 Hz. Thus, the peak noise in this case is produced by the bogie area noise

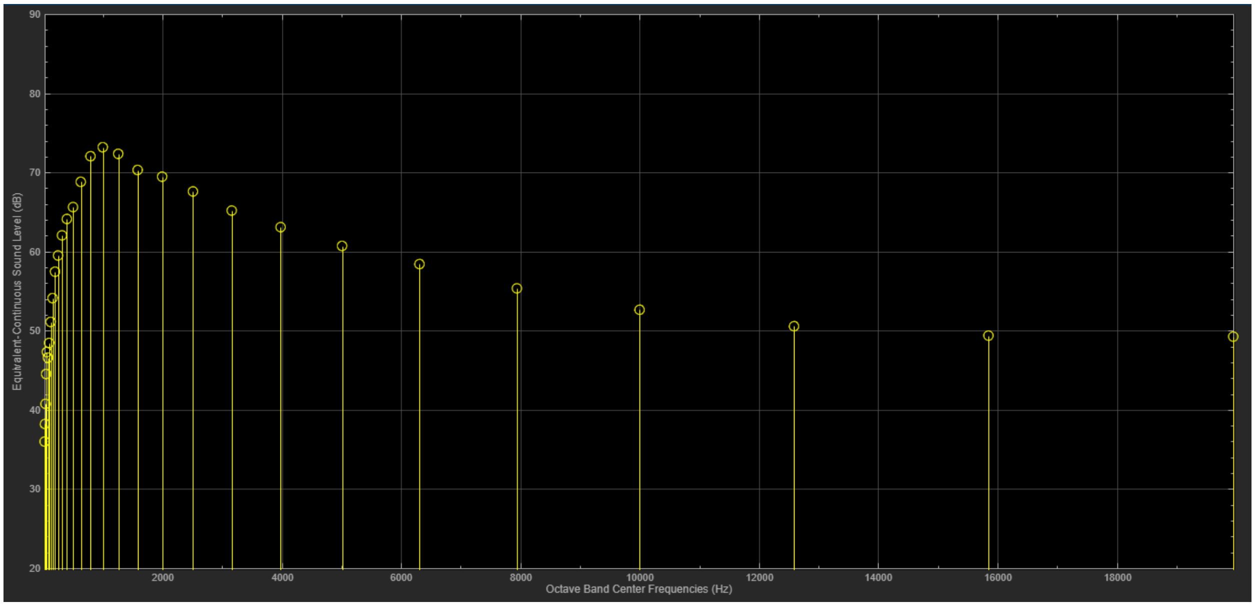

Figure 5: The spectrum of the high speed train noise in frequency domains

3.2 The reduction of the high speed railway noise by noise barrier

Construction of the noise barrier will be work efficient in the residential areas that are the most affected with the high frequency (HF) noise exposure from the HSR.

A residential area is built in the SoundPLan software along with the railway track passing through it, as discussed in the figure 2-3. A noise barrier of height 3 m is constructed along one side of the RT to investigate the effectiveness of the NB in the noise exposure as shown in the figure 6. The speed of the HSR is set 300 km/h and it passed through the residential area to investigate the impacts of noise exposure on the environment and on the residents living along the railway track.

The simulation results of the noise exposure of the HSR on the residents living nearby the RT is shown in the figure 7. It can be seen in the figure, the area with no NB exposed with more noise than one having NB.

The side with noise barrier absorbs noise coming from the HSR and resists in the transmission to the nearby area. The noise exposure reduced when it reaches to the buildings nearby the HSR railway track. The noise exposed by the building is less than 70 dB(A) which is according to the Japanese permitted standard.

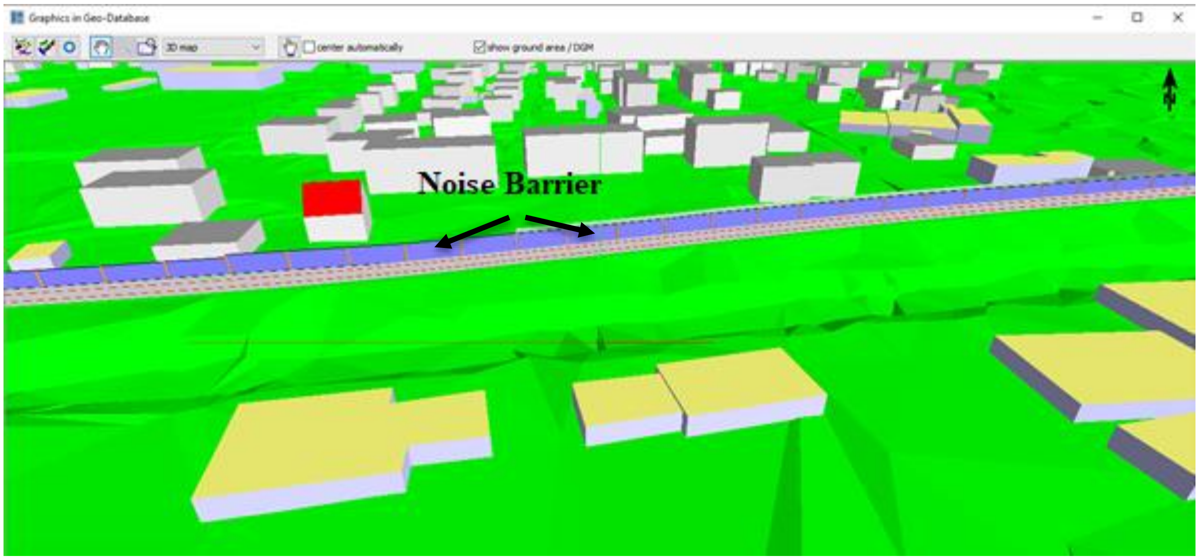

Figure 6: The Noise barrier along one side of the railway track

The maximum SPL noise exposure of the side having noise barrier across the railway track is reaches values in between 70-80 dB(A) to the nearby RT and reduced than far less than 70 dB(A) when it reaches to the residential and other noise sensitive areas. While, the other side with no noise barrier exposed to higher noise with more than 100 dB(A). The noise will remained between 90 and 100 dB(A) when it reaches at the residential buildings and countryside, which cause many problems for the residents living alongside of the railway track as shown in the figure 7. This high intensity noise caused the microbial production and growing ability and results in the reduced their colonial formation.

For the effectiveness of the noise barrier is dependent on the distance between the noise source (HSR) and the receivers (inhabitants), the noise barrier wall's material and the height of the NB. In order to get best control on the noise reduction the height of the NB should be higher to reduce much of noise. Also the distance between the source and the receiver must be large to get best results.

Although the NB installation is good option but it is one of the very expensive method to control the noise coming from the HSR, as it is built along the whole track. It is mentioned in the study of Hanson et al. [22] that, the noise barriers will only absorb the noise particular frequency range and depends on the thickness of the absorbing wall. Some frequency's sound may refract through the

NB if the distance between the source and the receiver is non-ideal [22] and the usefulness of the NB will be abridged.

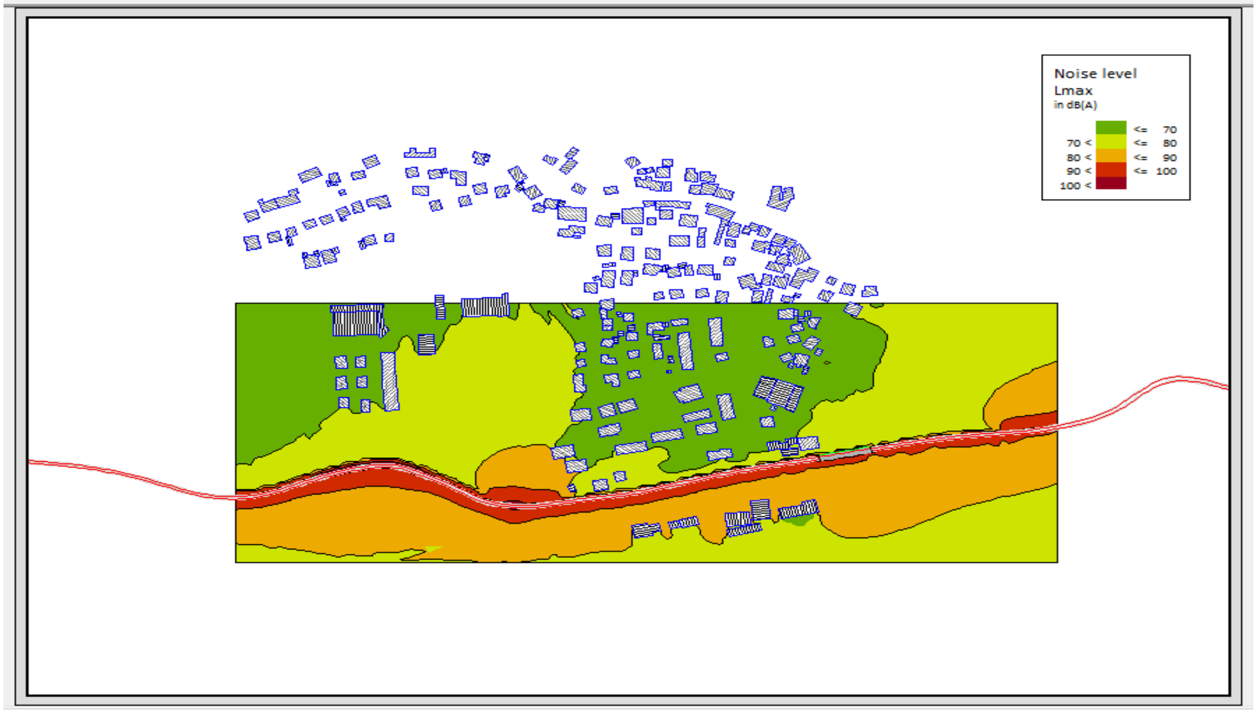

Figure 7: The noise exposure of the HSR on the residents living nearby the RT

It is practical and forthright approach to fabricate the NB between the HSR and the residents, but it is not absorbing the noise coming from the rooftop of the train (pantograph) and some of noise with particular frequencies may refract round the barrier structure. Some people may not like the method of building the NB across the RT, as they found unattractively sceneries. Also some passenger don't like the outer view might hide due to the construction of the noise barrier.

Anyhow the construction of the noise barriers is very expensive approach to reduce the noise of the HSR but it is long term method to control the noise coming from the lower components of the HSR. In order to get best results in the noise reduction, the NB height should be 2-4 m at least. The noise absorbing material with high rate of absorption will absorb more noise and reduce much of the noise transmission from the HSR to the receptors (Humans).

4. Conclusion

The SPL spectrum of the HSR passing-by Beijing railway station shows that, the major noise concentration is lies in the frequency range less than 2000 Hz. The peaks of the noise is shown at the frequency range between 500-1200 Hz frequency ranges. From the study [8], the noise produced by the bogie area consists of frequency range of 800-1200 Hz, so this peak noise is belongs to the bogie area noise. It is concluded the bogie area noise is leading noise of the HSR.

In the noise simulation of the HSR in the SoundPlan software, we built a noise barrier of height 3 m along one side of the railway track to investigate the reduction of the overall noise of the HSR. The maximum SPL noise exposure of the side having noise barrier across the railway track is reaches values in between 70-80 dB(A) to the nearby RT and reduced then far less than 70 dB(A) when it reaches to the residential areas. While, the other side with no noise barrier exposed to higher noise with more than 100 dB(A), which cause many problems for the microbial and the residents living alongside of the railway track. This study shows that, there is 10 dB(A) noise reduction in the overall noise of the HSR when we use noise barrier of height 3 m across the railway track. The recommended height of the noise barrier is 2-4 m at least. The noise absorbing material with high rate of absorption should be used to absorb more noise and reduce much of the noise transmission from the HSR to the receptors.

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Asif Mahmood, a Pakistani international student at Beihang Univeristy, Beijing, China. I am doing masters in mechanical engineering and my research area is noise control.

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Conflicts of Interest

There are no conflicts to declare.