Improved Methods for In-situ Measurement Railway Noise Barrier Insertion Loss

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Abstract: Many countries which seek to understand the acoustic performance of railway noise barriers have established standards for the conduct of in-situ experiments. However, there are no universally acknowledged receiver positions for the evaluation of the barrier performance, a fact which may be leading to uncertainty over the noise reduction capabilities of available barriers. In terms of the descriptor of the barrier performance, the general recommendation is the A-weighted sound pressure level, although the latter is considered to underestimate low frequencies for railway noise barrier. Thus, in this study, the comparison of receiver positions and the descriptors among existing Chinese, ISO and European standards were investigated. Based upon a combination of diffraction theory and standards, a rearrangement of receiver positions and one-third-octave-band analysis were proposed. In addition, in line with improved methods, an in-situ measurement of insertion loss for a 1.5 m high railway noise barrier was designed and conducted. The results of the experiment validate as effective and applicable the new receiver positions. These results also suggest that one-third-octave-band analysis is indispensable.

Key words: railway noise; noise barrier; in-situ experiment; A-weighting; insertion loss; one-third-octave-band analysis; grid receiver positions

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0 Introduction

Noise barriers, the most effective means to mitigate the propagation of sound, are widely applied on urban railway transit systems, especially on elevated lines. The noise reduction effect of a railway noise barrier is thought to depend largely on its height and the relative distance between the source, the barrier, and receiver positions[1]. But there is also a close relationship between acoustic performance and environmental factors, such as ground effect, atmospheric turbulence, air absorption, refraction by wind and temperature gradient profiles[2-3]. To achieve noise reduction effect of barriers on site during the operation of a real urban rail transit system, all factors must be taken into account. To this end, many countries have established guidance standards for in-situ experiments[4-6]. ISO 10847-1997[4] proposes that barrier performance in a field test can be represented by the difference in sound pressure levels at specified receiver positions before and after the installation of a barrier, provided that the relevant parameters remain unchanged. This is referred to as "insertion loss" or "attenuation". ISO 10847-1997 also proposes that naturally occurring railway traffic, principally the passenger train, should be used as the sound source equivalence for the "before" and "after" measurements.

However, there are no global standards for receiver positions, a state of affairs which produces vagueness. ISO 10847-1997 proposes that there are only two conditions: hemi free-field conditions, and reflecting surfaces. These conditions as a very general characterization of the open space behind barriers. In China's standard

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HJ/T 90-2004[5], receivers are defined as being located in the area which is the most sensitive to the noise. TB/T 3050-2002[7] defines the area sensitive to noise as residential buildings, schools, hospitals and other areas which require strong protection from noise. However, under different meteorological conditions, the shapes of areas are vulnerable to noise change. The standard is thus useful for getting a project accepted, but can be useless as a guide for designers who want to find the best barrier for a particular site. In China, in consequence, these standards have to be supplemented with other standards[7-10] for different receiver positions. The receiver position stated in TB/T 3050-2002, which is concerned with railway lines and used for the investigation of railway boundary noise in GB/T 12525-1990[8], directs a receiver position 30 m from the nearest track center and 1.2 m above the mean rail head height of the nearest track in the relevant area. GB/T 5111-2011[9], which is concerned with railway vehicle noise, directs that receivers be located 7.5 m away from lines and at heights of 1.5 m and 3.5 m. HJ 453-2008[10], which is concerned with testing the noise intensity of railway traffic, directs that the receiver should be placed 7.5 m away from the source and at a height of 1.5 m. Thus these given positions can be identified as alternative receivers in the case of comparing barrier performance with different shapes.

Seeking to clarify receiver positions in field experiments, the European Committee for Standardization (ECS) recently made recommendations for the measurement of sound attenuation of given noise barriers at given sites in given meteorological conditions. The ECS's standard, CEN/TS 16272-7: 2015[6], recommends nine locations to place the receivers, forming a grid, in order to measure the attenuation of a given noise barrier at a given site including given meteorological conditions. They are placed specifically at a distance of 7.5, 12.5 and 25 m away from lines and at a height of 3.5, 6.0 and 9.0 m. This standard is a useful source of comparison of the noise attenuation capacities of different types of barrier at the same site under the same meteorological conditions. However, although there are many researchers at work on the in-situ measurement of insertion loss in railway noise barriers[1,4-11], very few base themselves on this European standard[12].

In consequence, there are no universally accepted receiver positions for the evaluation of barrier performance. This circumstance may be leading to uncertainty with respect to the noise reduction capacities of barriers presently available.

As the most common descriptor for assessing the barrier performance, the equivalent continuous A-weighted sound pressure level[4-6] is introduced to calculate the attenuation of a barrier. The ISO standard[4] minimally requires field measurements of equivalent A-weighted sound levels, with and without barrier, for all receiver positions, producing a single-number attenuation rating. Chinese[5] and European[6] standards also adopt the latter as evaluation indicator. However, it is impossible to assess the performance of barriers at different sound frequencies using this single-number rating. In addition, A-weighting tends to devalue the effects of low frequency noise, making its suitability for the evaluation of noise barrier performance dubious. In recent years, many researchers have concluded[13-17] that A-weighting underestimates the annoyance produced by low-frequency and predominantly low-frequency noise, even at low volume levels. Despite the masking effects of higher level components in complex sound environments, the weakness of A-weighting have been identified[18-19] as well. Since barriers are mostly erected on the elevated section of lines, while relevant sound emissions are mainly concentrated at low frequencies[20], A-weighting is not a useful guide.

The present study aims to shed light on the measurement of insertion loss in railway noise barriers. In order to specify a set of reasonable receiver positions for comparing different types of barriers and to introduce a descriptor for the prediction of the acoustic performance of railway noise barriers, based on relevant standards and sound diffraction theory, an improved arrangement of receiver positions is put forward and a current indicator is taken into account as a supplement to the A-weighting method. Utilizing these, we designed and carried out an in-situ experiment to investigate insertion loss of railway noise barriers. For the experimental analysis, differences between recommended receiver positions and the reset receivers, sound pressure level (SPL) and attenuation in A-weighting method and the improved method were researched. In the following, we first describe the determination of receiver positions in the field experiment. We then describe sound pressure level acquisitions by different descriptors on the "before" and "after" measurements. Finally, we give the attenuation results for all receiver positions.

1 Improved Methods

1.1 Rearrangement of receiver positions based on the diffraction theory

In order to compare the insertion loss values of different types of barriers at the same site under given meteorological conditions, it is quite important to offer an approach to determine the receiver positions in the full-scaled experiment of barrier performance. In the case of noise barriers, receiver positions are located on the opposite side of the sound source. In accordance with diffraction theory[21], the open area behind the barrier can be divided into three zones: A bright zone where all frequencies transmit directly, a transition zone where low and middle frequencies bend around the barrier during the direct transition of high frequencies, and a shadow zone where, as a result of the vibration and the diffraction, only low-frequency sounds are transmitted. Since the noise reduction effects of barriers vary substantially by zone, and variations are a function of frequency[22], in-situ measurements of insertion loss for all frequencies in each zone are necessary. Depending on distance of receiver from sound source, the acoustic energy produced by the source will behave quite differently. In far field, the spherical shape of the sound waves can be reasonably approximated as a plane-wave, with no curvature[23]. It is important to understand this difference, and place the receiver positions in near field and far field separately when taking measurements. Generally, a far field acoustic begins two wavelengths from the sound source, and extends outward to infinity. In the case of traffic barriers, the start of the far field is at least around 14 m[23]. Receiver positions should therefore better be placed less and greater than 14 m, respectively. It is considered that receiver positions represent barrier performance at all the acoustic areas given above. A conservative estimate is that six positions meet the requirements (Table 1).

Table 1 Rearrangement of receiver positions based on diffraction theory

Distance from the nearest track center	
≤14 m	≥14 m
Bright zone in near field	Bright zone in far field
Transition zone in near field	Transition zone in far field
Shadow zone in near field	Shadow zone in far field

The prescribed receiver positions are shown in Fig. 1, where the height of barrier above the rail head height is 2 m. Different shadows based on diffraction theory show that for Chinese standards (indicated by triangles) all receiver positions are located in the shadow zone in near field, with the exception of the receiver in TB/T 3050-2002, which is located in the shadow zone in far field. All nine positions specified by CEN/TS 16272-7: 2015 (indicated by circles) cover four of the acoustic areas. M1-1, M2-1 and M2-2 represent the performance in the shadow zone in near field; M3-1, M3-2 and M3-3 represent the performance in the shadow zone in far field; M1-2 and M2-3 represent the performance in the transition zone in near field, while M1-3 represents the performance in the bright zone in near field. In addition, the sound pressure distribution of the whole of the open space behind the barrier is mapped by the nine grid positions, enabling visualization of the noise reduction effect of a barrier. The grid-form method is thus instructive for improving the arrangement.

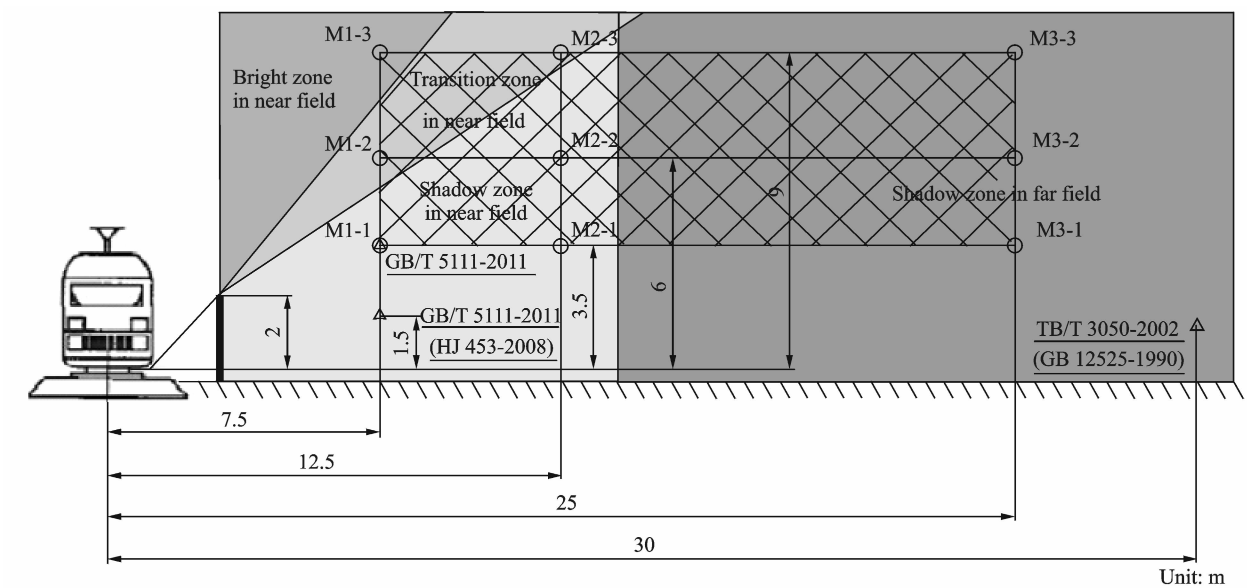

Fig. 1 Comparison of receiver positions prescribed according to the standards[4-10]

By considering the actual need of the engineering application in urban railway transit systems, the receiver positions have to be rearranged in terms of the changeable locations of the acoustic areas. For instance, if a barrier is installed on a bridge, it is difficult to reach the bright zone. Hence there is no necessity to place receivers at M1-3, M2-3 and M3-3 unless there are tall residential buildings close to the lines. If the sensitive areas are located far from the lines, receivers at M3-1, M3-2 and M3-3 can be placed around the sensitive area instead. When the height of the tested barrier is very low, the boundary dividing the shadow zone and the transition zone must be lower than that shown in Fig. 1. This means that receiver M1-1 can be located in the transition zone in near field, resulting in no receiver positions in the shadow zone in near field close to the barrier. If the shape is near to fully-enclosed, the receiver M1-3 should also probably be located in the shadow zone in near field, resulting in no receiver positions in the bright zone. In consequence, receiver positions need to be rearranged in all the acoustic areas as possible.

1.2 One-third-octave-band analysis

The ISO standard[4] recommends octave-band or one-third-octave-band sound pressure levels as indicators when it is necessary to obtain frequency characteristics of barrier insertion loss. Since the dominant frequency components are easily recognizable from one-third-octave-band analysis, this method has been adopted by low frequency noise standards of Polish, Swedish and German in general environment[13]. This has implications for the placement of barriers in areas proximate to urban main road traffic. It appears that such noise makes a smaller contribution to reported annoyance than might be inferred from the objective or physical dominance of the noise[24]. In such a case, it is unnecessary to analyze in-situ experimental results by employing one-third-octave-band analysis. The same applies with railway noise barriers, since it is well known that rolling stock noise is the predominant component of urban railway noise and that the latter is normally within a rather broad frequency range of 800 Hz to 2 500 Hz[25]. There are many other sources of noise, such as curve squeal, brake screech and bridges. The acoustic characteristics[26] of these are shown in Table 2. When a train crosses a viaduct, the low-frequency rumble noise induced is a significant annoyance for those in the station and residents in the vicinity, even at considerable distances. This is because lower frequency noise travels farther than higher frequency noise[23]. When sound barriers are installed on a viaduct, the additional low-frequency noise which radiates from the viaduct, the barrier and their related connectors cannot be neglected. One-third-octave-band analysis must be deployed here, since it produces data helpful to the attenuation of such low-frequency noise.

However, in the interests of reliability and applicability, real site testing is necessary. In our view, it is advisable to design an in-situ insertion loss experiment for railway noise barriers based on standards and our findings. This way, it is possible to compare the results of different analysis methods and to offer practicable suggestions.

Table 2 Dominant frequency range of noise sources (other than rolling stock noise) in urban rail transit systems

Special situation	Curve squeal	Brake screech	Bridge
Frequency range	Pure tone, high frequency (up to 10 kHz)	Pure tone, high frequency (during braking)	Low frequency

2 Experiment Design

Based on the improved methods, an in-situ experiment was conducted on Jiading Campus, Tongji University. A straight barrier, placed at ground level, with a thickness of 0.1 m, was tested. The length of the barrier was 10 m and its height above the track was 1.5 m, which is relatively lower than other railway noise barriers. Since the barrier could be removed during the period of experiment, utilizing the direct measurement method[4], sound pressures at receiver positions were tested by microphones before and after barrier installation. The noise source in the experiment was naturally occurring railway traffic: two-carriage passenger trains, each 22 m long. Since the experiment sites were located in the middle of the lines, the noise induced by trains in brake mode could not be considered. The trains traveled at 40 km/h as they passed the test field.

The circles in Fig. 2 indicate the directed receiver grid formation. Applying the improved methodology, it was evident that M1-2 and M1-3 could not be located in the transition zone, on account of the low profile of the barrier. The attenuation property of receiver M1-1, located far from the barrier and close to the transition zone in near field, might underestimate the performance of the barrier in the shadow zone in near field. Moreover, since the barrier was installed at the ground line, it proved possible to choose the receiver above ground at 1.2 m to simulate pedestrian hearing. Thus receiver positions were better reset close to the barrier and to the ground. In consideration of the low profile, it was possible, by applying the grid-formation criteria of the standards, to determine receiver positions. These are indicated by crosses in Fig. 2. They were at a distance from the nearest track center of 3.3, 9 and 18 m and at a height above the mean rail head of the nearest track of 1.2, 1.8 and 2.5 m, respectively. As per the discussion above, the receiver positions in our experiment were set in four areas of the open space behind the barrier. P1-1, P2-1, P2-2 and P2-3 are represented in the shadow zone in near field. P3 is represented in the shadow zone in far field. P1-2 is represented in the transition zone in near field. P1-3 is represented in the bright zone in near field.

The microphones at each receiver position were omnidirectional and protected by windscreens. Corresponding frequency responses ranged from 20 Hz to 20 kHz. The sampling frequency of the sound pressure signals was intended to be 51.2 kHz, based on the Nyquist Theorem. To avoid message distortion, this was more than twice the maximum frequency component of the audio frequency (20 Hz—20 kHz). The experiments on the "before" and "after" sites were conducted on sunny days only a few days apart. Meteorological conditions were not significantly different and thus were not measured. However, an acoustic amplifier, an electrical charge amplifier, sound pressure collecting equipment, an A/D data collection card and a computer running a data collecting program were prepared. These instruments met the requirements of EN 61672-1 and the microphones complied with IEC 61672 class 1. Pressure signals at all receiver positions were recorded simultaneously and, to ensure the statistical representativeness of the sample, train-passing data for each distance was obtained by taking at least 10 measurements.

3 Results

3.1 Signal processing procedure

According to the relevant standards[4-6], the equivalent continuous A-weighted sound pressure level can be represented as follow

$$L_{p\mathrm{Aeq},T_{\mathrm{pass}}}=10\log_{10}\left[\frac{1}{T_p}\int_{t_1}^{t_2}\frac{p_{\mathrm{A}}^2(t)}{p_0^2}\mathrm{d}t\right]=10\log_{10}\left[\frac{1}{N}\sum_{n=1}^{N}\frac{p_{\mathrm{A}}^2(n)}{p_0^2}\right] \quad (1)$$

where T_p is the train pass-by time interval, p_A is the A-weighted instantaneous sound pressure, and p_0 is the reference sound pressure (20 μPa). During the post-processing procedure, the sound pressure signals were first filtered by the band-pass of audio frequency range and A-weighting filter, and then, by utilizing the time interval of the train's passing, the equivalent continuous A-weighted sound level $L_{p\mathrm{Aeq},T_{\mathrm{pass}}}$ was obtained.

Since the valid pressure signals at each position were measured at least 10 times, equivalent levels had to be expressed as an average. The formula for the averaging method is

$$L_{\mathrm{Aeq}}=10\log_{10}\frac{1}{n}\sum_{i=1}^{n}10^{0.1L_{AE,i}} \quad (2)$$

where L_{Aeq} is the sound level used to calculate the noise attenuation of the barrier, and $L_{AE,i}$ is the i th pass-by level computed by Eq. (1). Hence, it was easy to obtain the attenuation single-number rating for barrier performance.

The C-weighted level and the 1/3 octave band level was acquired in the same way, producing an effective supplement to the A-weighting method. However, for the sake of simplification, the attenuation of each 1/3 octave band was obtained by calculating the ratio of sound energy in the field with and without the barrier. This is given by

$$\mathrm{Att}(f_{\mathrm{oct}})=10\log_{10}\left(\frac{\sum_i^N p_{wo}^2(f_i)}{\sum_i^N p_w^2(f_i)}\right) \quad (3)$$

where $p(f)$ is the sound pressure with respect to a certain frequency, calculated by applying the Fast Fourier Transform formula. f_{oct} is the central frequency of the 1/3 octave band.

3.2 Sound pressure level

To reach an assessment of barrier performance, the experimental results of the sound pressure level at all receiver positions on the "before" and "after" measurement will be illustrated first. This is in order to comprehend the characteristics of railway noise at a speed of 40 km/h. In Fig. 2, the bold numbers denote the continuous equivalent A-weighted sound pressure level (L_{Aeq}) at all receiver positions before the installation of the barrier. The italicized numbers denote L_{Aeq} on the "after" site. It can be seen that before the installation of the barrier, L_{Aeq} at P1-1 was marginally higher than that at P1-2 and higher than that at P1-3. Since the P1-1 and P1-2 positions were much closer to the track, the results confirmed that rolling stock noise produced by wheel-rail contact vibrations, could be a predominant component of railway traffic noise. However, P1-1 level was significantly lower than P1-2 and P1-3 around 5 dB(A) after the barrier was installed, indicating that the barrier was able to suppress rolling stock noise effectively. Performance of the barrier was particularly good in the shadow zone in near field. At the receiver-source distance of 9 m, the levels of each of the three receiver positions were almost the same on the "before" site, whereas the P2-3 level was much higher than P2-1 and P2-2 on the "after" site. With increase of receiver-source distance, L_{Aeq} showed a tendency to decrease at the same height, regardless of the installation of the barrier: P1-1>P2-1>P3 (L_{Aeq}), P1-2>P2-2 (L_{Aeq}) and P1-3>P2-3 (L_{Aeq}). Interestingly, in contrast to the " before " site, the

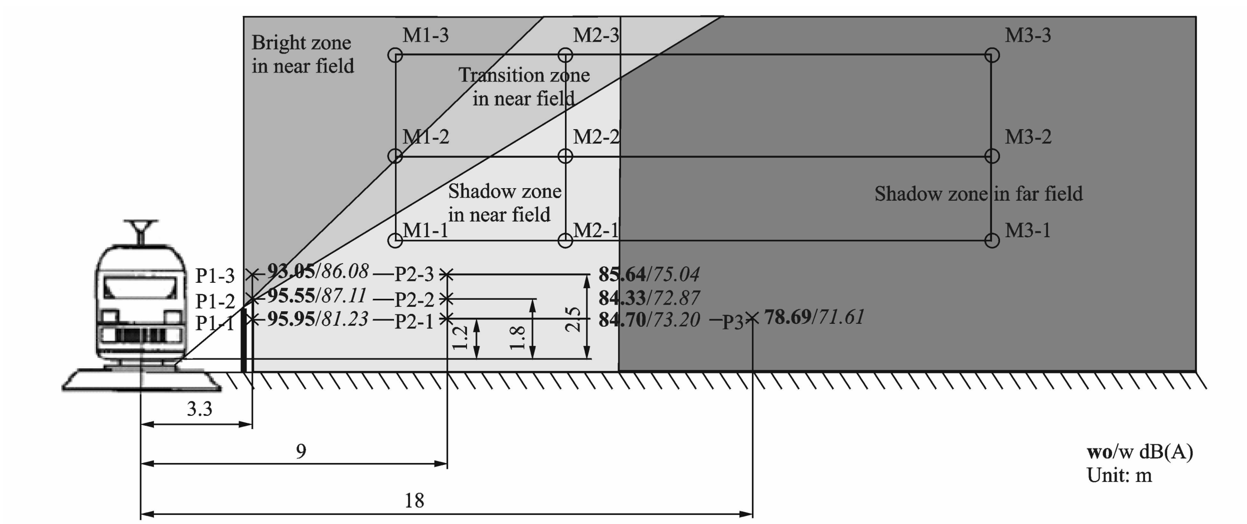

Fig. 2 Configurations of the in-situ experiments with the straight barrier on the ground line (frequency range: 20 Hz—20 kHz)

downward trend of the A-weighted level near the ground became slower on the "after" site.

By one-third octave analysis, SPLs at all receiver positions on the "before" site in Fig. 3(a) show that the dominant frequency range of railway noise was quite wide: five 1/3 octave bands of 400, 500, 630, 800 and 1 000 Hz, which are given relatively small weights by A-weighting[27]. Moreover, the maximum values at all receiver positions were, coincidently, all at 800 Hz, and the differences between the L_{Aeq} s and the maximum values at all the positions were no more than 1 dB (Table 3). Therefore, without one-third-octave-band analysis, the continuous equivalent A-weighted sound pressure level could present almost the same level as that of the predominant component. This indicated that A-weighting was suitable to describe the annoyance induced by railway noise. On the "after" site (Fig. 3(b)), sound levels in the dominant range of railway noise were roughly consistent with the levels at low frequencies, which were reduced considerably by the barrier. In order to understand the importance of low frequency noise, the difference between C- and A-weightings has been considered as a predictor since it indicates the amount of low frequency energy in the noise[14]. If the difference is greater than 15 dB, there is a potential for low frequencies. In Table 4, we see that the differences between A-weighted and C-weighted levels at all positions were as large as 6 dB. Although the differences were not too large, it is noteworthy that low frequency noise played the same significant role as the middle and high frequencies on the "after" site. This should not be neglected in the future attenuation research.

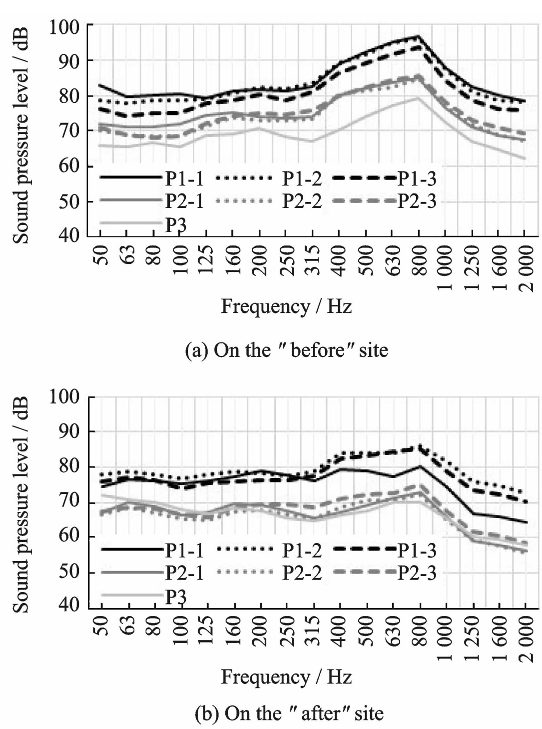

Fig. 3 Sound pressure levels in the one-third-octave band at all receiver positions

Table 3 Comparison between L_{Aeq} and maximum value of 1/3 octave band on the "before" site

Receiver position	P1-1	P1-2	P1-3	P2-1	P2-2	P2-3	P3
L_{Aeq}(20-20 kHz) /(dB(A))	95.95	95.55	93.05	84.70	84.33	85.64	78.69
800 Hz of 1/3 octave band/dB	96.76	96.24	93.75	84.88	84.69	85.64	79.02
Absolute difference	0.81	0.69	0.70	0.18	0.36	0.00	0.33

Table 4 Differences between A-weighted and C-weighted SPL at all positions on the "after" site dB

P1-1	P1-2	P1-3	P2-1	P2-2	P2-3	P3
4.73	3.06	2.88	4.38	4.09	3.73	6.15

3.3 Insertion loss

Insertion loss, also called attenuation, is defined[4] as the difference in sound levels at a specified receiver position before and after the installation of a barrier. Using the results of SPLs at all the receiver positions analyzed above, barrier attenuation was obtained and listed in Table 5. It appears that the barrier varied in effectiveness depending on where the receiver position was located. Of the seven positions, the attenuations in the shadow zone in near field (P1-1, P2-1, P2-2 and P2-3) were the highest, being at least 10 dB (A). The next were in the transition zone in near field (P1-2) and in the shadow zone in far field (P3). The lowest was in the bright zone in near field (P1-3). Hence the area in the shadow zone in near field appears to be the major area of competence for the noise reduction effect of the barrier. Since the difference between the maximum and the minimum values of the attenuations (P1-1 and P1-3) was around 7 dB(A), it is evident that a single measurement point cannot provide a comprehensive presentation of barrier performance. In other words, the significant difference between these attenuations is attributable to variation among receiver positions. These must be taken into account when evaluating the acoustic performance of barriers.

Table 5 Attenuations in L_{Aeq} at all receiver positions (frequency range: 20 Hz—20 kHz) (dB(A))

P1-1	P1-2	P1-3	P2-1	P2-2	P2-3	P3
14.72	8.44	6.97	11.50	11.46	10.60	7.08

For comprehension of the frequency characteristics of the attenuation, the attenuations in the one third octave band from 50 to 2 000 Hz are computed and shown in Fig. 4. The barrier performed well in the dominant frequency range of these five bands, especially in the shadow zone in near field (P1-1, P2-1, P2-2 and P2-3). Attenuations at all receiver positions were as high at the frequencies above the dominant range. However, the attenuations in the range of low frequencies were ultra-low, and, below the band of 100 Hz, even negative. Among all the receiver positions, the maximum of excess attenuation was 6.3 dB in the band of 50 Hz at receiver P3. Ground effect and diffraction of low frequencies at the top of the barrier might be the cause of negative values of attenuation located primarily in the shadow zone in far field (P3), the transition zone in near field (P1-2) and the bright zone in near field (P1-3). In summary, the barrier performed quite well in the range of mid and high frequencies, but relatively badly at low frequencies.

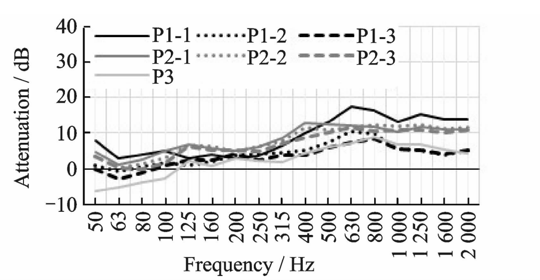

Fig. 4 Attenuations in the one-third-octave band at all receiver positions (20—5 000 Hz)

4 Discussion

By utilizing the grid-form method, attenuation at the recommended positions could be estimated by known results. It appears that the maximum value of attenuation at all recommended positions can be located at receiver M1-1 and M1-2. As receiver M1-1 is close to the boundary between the transition zone and the shadow zone, based on diffraction theory, the attenuation at receiver M1-1 must be a little lower than that at receiver P1-2, which is located in the transition zone in near field. In the same way, attenuation at receiver M2-1 must be a little lower than that at receiver P2-3. It follows that maximum attenuation in the shadow zone in near field is no more than 10 dB(A). Compared with the experimental results in section 3, the attenuations at the recommended positions definitely underestimate the performance of the barrier. As such, the recommended receiver positions seem to be higher than the evaluation requirement, and hence unsuited to low-height barriers. With the rearrangement of receiver positions much closer to the barrier and to the ground, the attenuations in L_{Aeq} in the bright zone, the transition zone and in the shadow zone in near and far field can be demonstrated more completely and distinguished more clearly. In consequence, it would be better to rearrange receiver positions to suit the actual need of the barrier.

Using one-third-octave-band analysis, the predominant frequency range of railway noise can be identified. Moreover, the frequency characteristics of the attenuation can also be recognized: The barrier performed well at the predominant frequency range of railway noise but relatively poorly at low frequencies and at frequencies below 100 Hz in particular. It is of interest to note that there is considerable variation in attenuation even in the same frequency band. Although A-weighting is inapplicable here, the single-number rating can be still utilized as a railway noise indicator. Overall, the A-weighting method is inadequate to the analysis of the performance of railway noise barriers. However, a combination of A-weighting method and one-third-octave analysis can rectify the problem.

5 Conclusions

Based on diffraction theory, we have proposed here an improved method for the arrangement of receiver positions for the in-situ measurement railway noise barrier insertion loss. The method is capable of optimizing the performance of railway noise barriers in all the areas behind barriers. Our in-situ investigation of insertion loss with low-height barriers validates the claim that this method is more effective than CEN/TS 16272-7. The A-weighted SPL led to the overrating of the railway noise barrier performance with respect to the SPL. We conclude that one-third-octave band analysis provides superior frequency domain results, and is a good supplement to the A-weighting method. The one-third-octave-band values seem to provide a better general description of barrier performance than do A-weighted results.

This study may have limitations. Our experiment was conducted on barriers situated at ground level and as such our directions might not suffice to indicate low frequencies after barrier installation. Future research will seek to rectify this through experiments on elevated line sections. Nevertheless, to the extent that our study indicates how to achieve railway noise barrier performance from the measurement of sound pressure levels by the improved arrangement of receiver positions and one-third-octave analysis, it is a step toward better understanding.

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