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Research Article

Experimental Evaluation of Vibration Damping Performance in Floating and Standard Rail Fastening Systems Using Impact Hammer Testing

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Abstract

Railway fastening systems play an important role in reducing vibrations and noise, which are major issues in modern train infrastructure. This paper gives an experimental evaluation of the vibration-damping performance of floating and standard rail fasteners using drop hammer impact testing. It highlights the recommended measurement parameters as per the international standards, including BS EN 13146-3:2012 Railway applications -Track -Test methods for fastening systems (Part 3: Determination of attenuation of Impact loads). To replicate dynamic loading circumstances, a 50 kg mass was dropped from heights ranging from 50 mm to 150 mm, and vertical acceleration was measured at rail, sleeper, and ground levels using a frequency range of 1-200 Hz. The findings show that the floating rail fastener (FRF) greatly lowers ground vibrations when compared to the standard rail fastener (SRF), with damping effects ranging from 0.47 dB at 75 cm to 1.53 dB at 150 mm. The floating fastener significantly reduces vibrations transmitted to the sleeper and ground by exhibiting increased energy absorption at the rail at higher frequencies (over 16 Hz). On the other hand, the rigid design of the typical fastener causes more ground vibrations, especially at lower frequencies (1–12.5 Hz). These results demonstrate how well the floating fastener reduces environmental vibrations, which makes it a great option for cities and noisy places. For heavy-duty applications, however, the trade-off between structural stability and vibration reduction must be taken into account. This paper offers useful recommendations for improving railway infrastructure design and minimizing environmental effects by presenting empirical insights into the dynamic behavior of rail.

Keywords

Vibration Damping, Impact Hammer Testing, Floating Fastener, Standard Fastener, Ground Vibration Acceleration, Railway Infrastructure, Dynamic Loading

1. Introduction

Railway transportation is a critical component of modern infrastructure, enabling efficient and sustainable travel for passengers and freight. However, the dynamic forces created by moving trains, especially at high speeds or with large loads, can cause significant vibrations and noise [1]. These vibrations not only compromise the structural integrity of railway

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rails, but they also have a negative influence on the surrounding environment and human health. Studies have connected traffic noise to a variety of health problems, including sleep disturbance [2], discomfort [3], cardiovascular consequences [4], and disorders like hypertension and ischemic heart disease [5]. With traffic accounting for more than half of urban noise pollution [6], there is an urgent need to reduce these effects through novel technical solutions.

To solve these issues, rail fastening systems have developed as key components for preserving track stability, reducing vibrations, and managing noise. Among the numerous types of fastening systems, floating rail fasteners have attracted attention for their capacity to dampen vibrations and minimize noise, although standard fasteners are extensively utilized for their rigidity and low cost. Understanding the comparative performance of these systems under dynamic loading situations is critical for improving railway design and assuring long-term operation [7].

Extensive research has been undertaken to assess the efficacy of rail fastening systems under dynamic load situations. For example, floating slab tracks have been demonstrated to minimize ground-borne vibrations by up to 10 decibels compared to conventional tracks [8]. Similarly, flexible fastening techniques have shown a significant reduction in vibrations transmitted to the sleeper and ground [9]. However, much prior research has concentrated on theoretical modeling or field observations, creating a gap in our understanding of these systems' fundamental behavior under controlled laboratory circumstances. This study attempts to close this gap by using systematic drop hammer impact testing to assess the vibration damping performance of floating and standard rail fasteners over a wide range of impact energy and frequencies.

The main goals of this study are to evaluate experimentally the performance of floating and standard rail fasteners in terms of vibration damping and vertical acceleration under dynamic impact loading. It aims to measure the damping effectiveness of floating fasteners in comparison to standard fasteners across a variety of impact energy and frequencies, as well as to compare the vibration transmission properties of both fastening systems at the rail, sleeper, and ground levels. With an emphasis on maximizing the performance of railway infrastructure and minimizing environmental effects, the study also aims to offer insightful information that will help direct the design and selection of rail fastening systems [10].

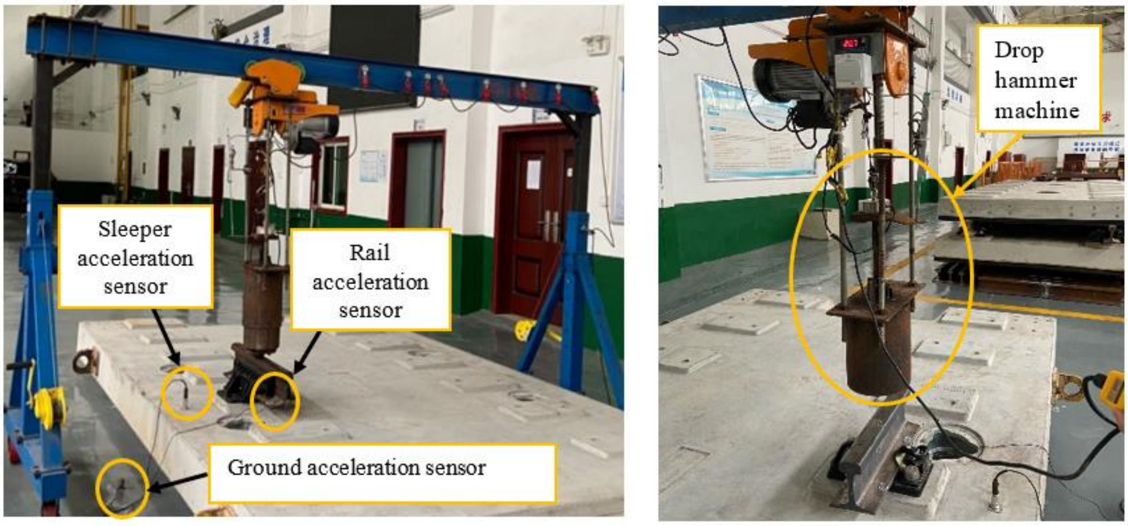
This work adds to the increasing amount of information on railway vibration damping by offering empirical data on the performance of standard and floating rail fasteners in controlled laboratory settings. The results provide guidance on the selection and optimization of fastening systems for various operational and environmental requirements, which has practical consequences for railway engineers and policymakers. This study backs the creation of environmentally friendly railway infrastructure that strikes a balance between cost, performance, and environmental impact.

2. Experimental Setup and Procedure

A drop hammer impact testing device was used to experimentally assess the vibration damping capability. To replicate dynamic loading circumstances, a 50 kg mass was dropped from heights of 50 mm, 75 mm, 100 mm, 125 mm, and 150 mm. Acceleration sensors installed at the rail, sleeper, and ground levels were used to monitor the impact forces produced during the testing. The usual vibration spectra of railway systems are covered by the frequency range of interest, which was selected at 1–200 Hz.

To assess the performance of standard and floating rail fasteners under dynamic impact stress [11], the experimental setting for this investigation was meticulously planned [12]. A 50-kilogram steel ball was suspended from a steel wire and pulley system as part of a drop hammer mechanism. By enabling regulated vertical hits on the rail, this configuration guaranteed reliable and repeatable loading conditions. To give a thorough comparison of their performance, tests were conducted on both floating and standard rail fastening systems, including all related parts such baseplates and fastener assemblies.

High-precision acceleration sensors [13] were positioned at the rail, sleeper, and ground levels in order to record detailed data. In addition to measuring vertical acceleration, these sensors offered vital information on how vibrations spread throughout the railway network. Real-time data gathering, processing, and analysis were made possible by the sensors' connection to an advanced data acquisition system integrated with a computer. A strong framework for assessing the performance of the two fastening systems under dynamic impact conditions was established thanks to this configuration, which made it possible to accurately capture acceleration time-domain curves and other vibration metrics.



(A). Floating Fastener (B). Standard Fastener

Figure 1. *(A) And (B) shows the schematic diagram of the drop weight impact testing setup.*

3. Results and Analysis

Each measuring point's acceleration signals are analyzed at a 1/3 octave using software for data collecting and signal processing [14].

Given the difficulty in controlling the hammering force throughout the test, the acceleration at each measuring point is normalized to a unit force when comparing the 1/3 octave analysis results [15]. The hammering force for each fastening systems were about 35-40kN in the test. The analysis of the vertical acceleration of the rail for standard and floating fasteners across various heights and frequencies reveals some interesting findings.

At a height of 50 mm, within the frequency range of 1 to 200 Hz, the vertical acceleration of the standard fastener is greater than that of the floating fastener from 1 Hz to 12.5 Hz. However, starting from 16 Hz, the floating fastener demonstrates greater vertical acceleration than the standard fastener, as illustrated in Figure 3(A). The maximum vertical acceleration level for the floating fastener reaches 131.56 dB at 80 Hz, while the minimum is 86.38 dB at 6.3 Hz. The standard fastener's maximum vertical acceleration is 131.95 dB at 200 Hz, and the minimum is 90.78 dB at 12.5 Hz.

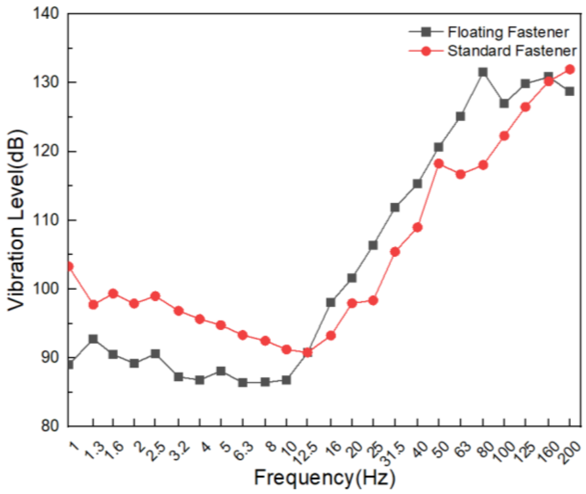
At a height of 75 mm, the trend changes. Here, the vertical acceleration of the floating fastener exceeds that of the standard fastener across the frequency range. The maximum vertical acceleration of the floating fastener remains the same as before, at 131.56 dB at 80 Hz, and the minimum is again 86.38 dB at 6.3 Hz. The standard fastener has a maximum vertical acceleration of 131.95 dB at 200 Hz and a minimum of 90.78 dB at 12.5 Hz, consistent with the previous data shown in Figure 3(B).

When examining a height of 100 mm, from 1 Hz to 12.5 Hz, the vertical acceleration of the standard fastener is still greater than that of the floating fastener. However, from 16 Hz onwards, the floating fastener shows greater vertical acceleration. The maximum vertical acceleration for the floating fastener is 138.16 dB at 160 Hz, with a minimum of 77.16 dB at 1 Hz. The standard fastener's maximum is 137.49 dB at 160 Hz, and the minimum is 96.7 dB at 12.5 Hz, as indicated in Figure 3(C).

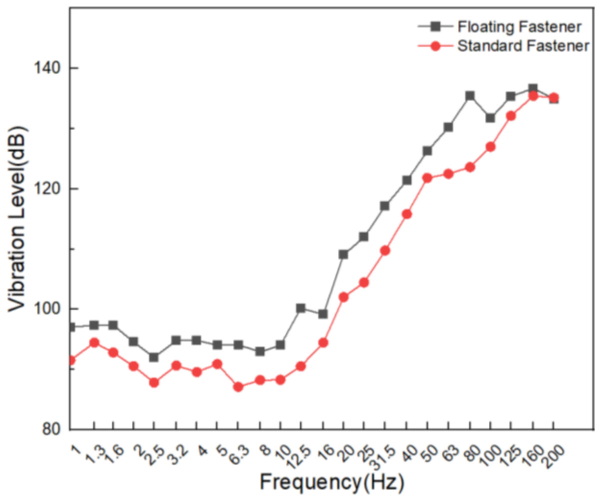
At a height of 125 mm, the same pattern holds. The standard fastener exhibits greater vertical acceleration from 1 Hz to 12.5 Hz, while the floating fastener surpasses it from 16 Hz onwards. Again, the maximum vertical acceleration for the floating fastener is 139.03 dB at 160 Hz, with a minimum of 79.98 dB at 1.6 Hz. The standard fastener peaks at 138.96 dB at 160 Hz and has a minimum of 98.99 dB at 12.5 Hz, as seen in Figure 3(D).

Finally, at a height of 150 mm, the vertical acceleration pattern is similar. The standard fastener shows greater acceleration from 1 Hz to 12.5 Hz, while the floating fastener exhibits a higher level from 16 Hz onwards, as shown in Figure 3(E). In this case, the maximum vertical acceleration for the floating fastener is 139.93 dB at 160 Hz, with a minimum of 78.2 dB at 1 Hz. The standard fastener's maximum is 140.77 dB at 160 Hz, and the minimum is 94.18 dB at 10 Hz.

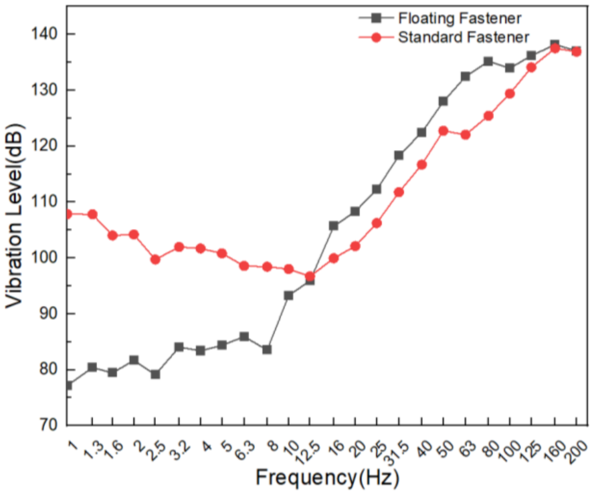
In summary, across various heights, the vertical acceleration characteristics of the floating fastener tend to surpass those of the standard fastener beyond 12.5 Hz, demonstrating a clear frequency-dependent behavior.



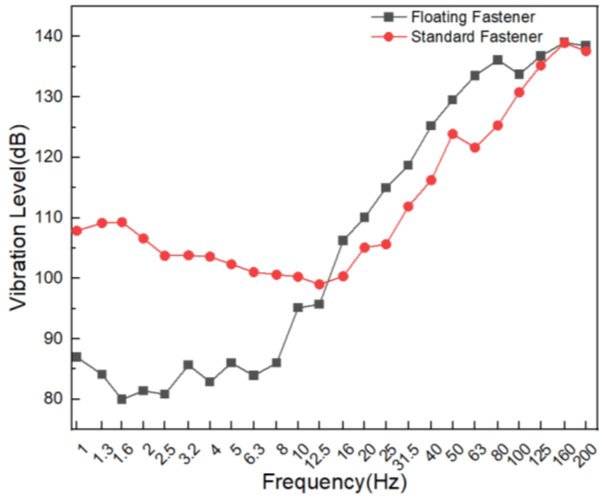
(A) 50mm



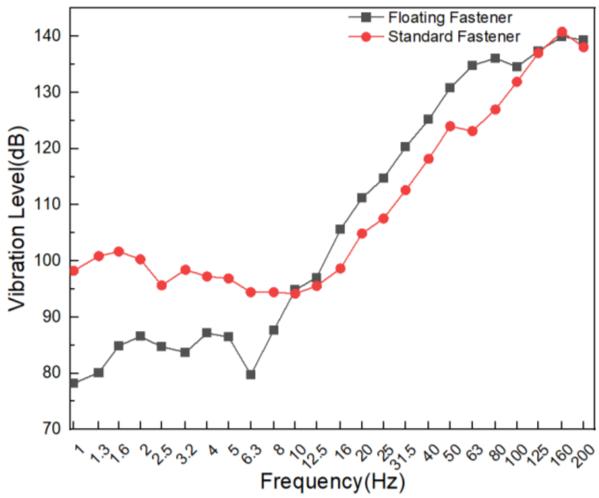
(B) 75mm



(C) 100mm

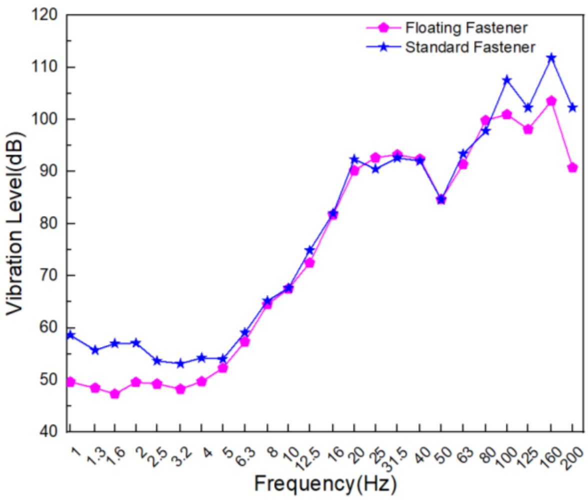


(D) 125mm

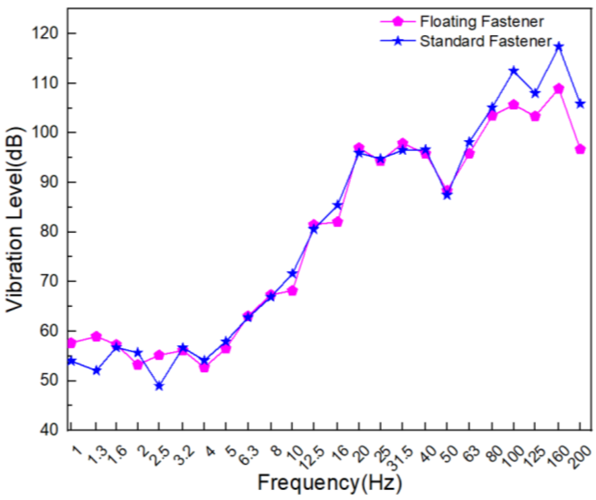


(E) 150mm

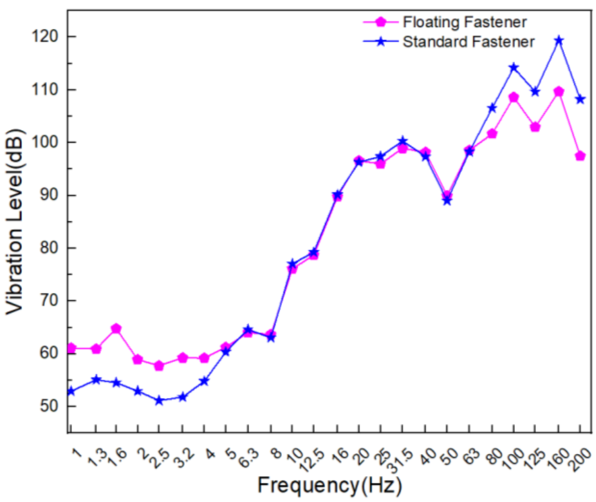
Figure 2. *Comparison of Rail of Floating Fastener to Standard Fastener at different heights.*



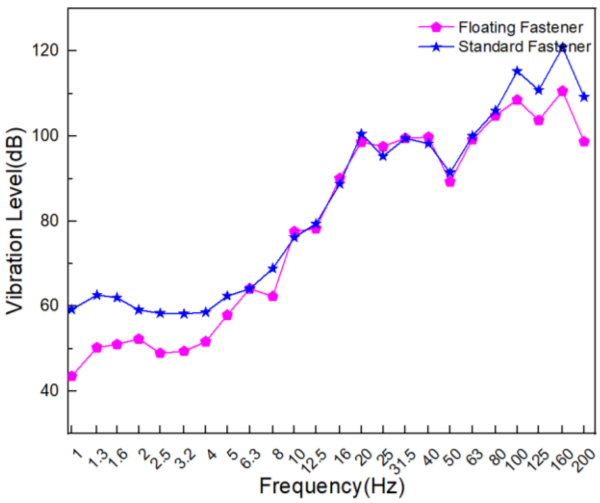
(A) 50mm



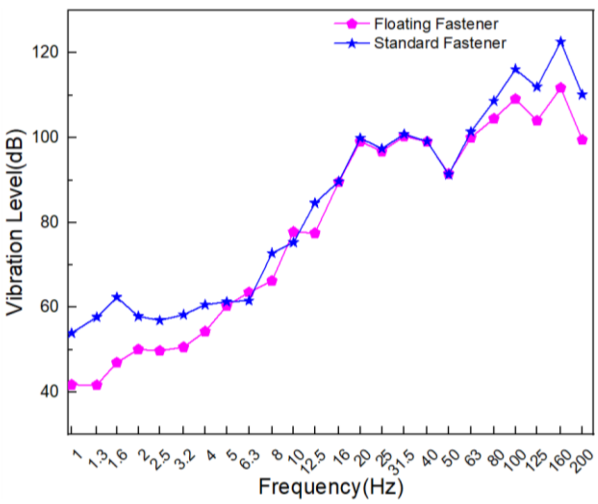
(B) 75mm



(C) 100mm



(D) 125mm



(E) 150mm

Figure 3. *Comparison of sleeper of the floating fastener with the standard fastener at different heights.*

Within the frequency range of 1 to 200 Hz at a height of 50 mm, the vertical acceleration of the sleeper equipped with the standard fastener is greater than that of the floating fastener, as illustrated in Figure 4(A). The maximum vertical acceleration level of the sleeper with the floating fastener reaches 103.55 dB at 160 Hz, while the minimum level is 48.26 dB at 3.2 Hz. In contrast, the standard fastener's sleeper exhibits a maximum vertical acceleration of 111.82 dB at 160 Hz and a minimum of 53.14 dB at 3.2 Hz.

At a height of 75 mm, the vertical acceleration of the rail with the floating fastener exceeds that of the standard fastener within the same frequency range of 1 to 200 Hz, as shown in Figure 4(B). The maximum vertical acceleration for the rail of the floating fastener is 108.94 dB at 160 Hz, with a minimum of 52.73 dB at 4 Hz. For the rail of the standard fastener, the maximum vertical acceleration is 117.41 dB at 160 Hz, and the minimum is 48.97 dB at 2.5 Hz.

At a height of 100 mm, the vertical acceleration of the sleeper with the floating fastener is greater than that of the standard fastener from 1 Hz to 6.3 Hz. From 8 Hz onwards, the floating fastener shows a greater vertical acceleration than the standard fastener, as illustrated in Figure 4(C). The maximum vertical acceleration level of the rail with the floating fastener is 109.7 dB at 160 Hz, and the minimum is 77.16 dB at 2.5 Hz. The rail with the standard fastener exhibits a maximum vertical acceleration of 119.39 dB at 160 Hz, and a minimum of 51.2 dB at 2.5 Hz.

At a height of 125 mm, the vertical acceleration of the sleeper with the standard fastener is greater than that of the floating fastener, as seen in Figure 4(D). The maximum vertical acceleration level for the rail of the floating fastener is 108.54 dB at 100 Hz, with a minimum of 43.47 dB at 1 Hz. Conversely, the rail with the standard fastener has a maximum vertical acceleration of 120.88 dB at 160 Hz and a minimum of 58.17 dB at 3.2 Hz.

Finally, at a height of 150 mm, the vertical acceleration of the sleeper with the standard fastener remains greater than that of the floating fastener, as demonstrated in Figure 4(E). The maximum vertical acceleration level of the rail with the floating fastener is 111.75 dB at 160 Hz, with a minimum of 41.64 dB at 1.3 Hz. In comparison, the rail with the standard fastener achieves a maximum vertical acceleration of 122.64 dB at 160 Hz and a minimum of 53.92 dB at 1 Hz.

Within the frequency range of 1 to 200 Hz at a height of 50 mm, the vertical acceleration of the ground with a standard fastener is greater than that of the floating fastener, as shown in Figure 5(A). The maximum vertical acceleration level of the ground with the floating fastener reaches 86.67 dB at 80 Hz, while the minimum vertical acceleration is 76.49 dB at 1 Hz. In contrast, the maximum vertical acceleration of the rail with the standard fastener is 92.44 dB at 100 Hz, and the minimum vertical acceleration is 18.26 dB at 2 Hz.

At a height of 75 mm, the pattern remains similar, with the vertical acceleration of the ground under the standard fastener exceeding that of the floating fastener, as depicted in Figure 5(B). The maximum vertical acceleration level of the rail of the floating fastener is 91.55 dB at 80 Hz, while the minimum is 10.1 dB at 1.3 Hz. Conversely, the maximum vertical acceleration of the rail of the standard fastener reaches 97.5 dB at 100 Hz, and the minimum is 22.62 dB at 1 Hz.

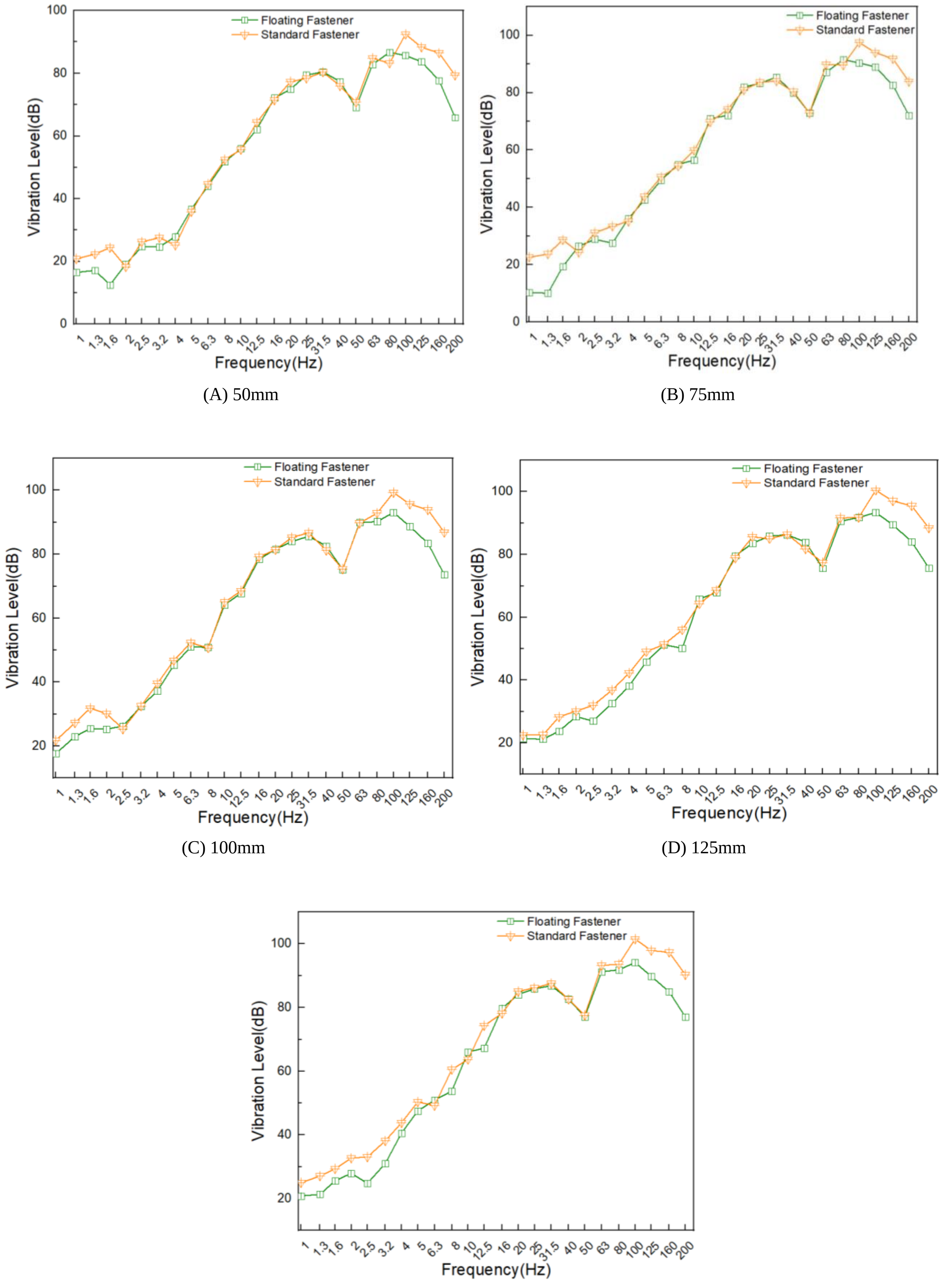
At 100 mm height, the trend continues, with the vertical acceleration of the ground beneath the standard fastener being greater than that of the floating fastener, as shown in Figure 5(C). The maximum vertical acceleration level of the rail of the floating fastener is 93.09 dB at 100 Hz, while the minimum is 17.64 dB at 1 Hz. Meanwhile, the standard fastener's rail achieves a maximum vertical acceleration of 99.31 dB at 100 Hz, with a minimum of 21.75 dB at 1 Hz.

When examining a height of 125 mm, the vertical acceleration of the ground with the standard fastener remains greater than that of the floating fastener, as illustrated in Figure 5(D). The maximum vertical acceleration level of the rail of the floating fastener is 93.36 dB at 100 Hz, and the minimum is 21.15 dB at 1.3 Hz. In comparison, the standard fastener's maximum vertical acceleration of the rail is 100.45 dB at 100 Hz, with a minimum of 22.51 dB at 1 Hz.

At a height of 150 mm, the vertical acceleration of the ground under the standard fastener continues to exceed that of the floating fastener, as seen in Figure 5(E). The maximum vertical acceleration level of the rail of the floating fastener is 94.16 dB at 100 Hz, while the minimum is 20.82 dB at 1 Hz. The standard fastener’s maximum vertical acceleration reaches 97.35 dB at 160 Hz, and the minimum is 24.93 dB at 1 Hz.

The frequency range of 1–200 Hz will be divided into the following bands: low frequencies: 1–20 Hz, mid-how frequencies: 20–50 Hz, mid-high frequencies: 50–100 Hz, high frequencies: 100–200 Hz as shown in Table 1. These bands are chosen because they represent distinct vibration characteristics in railway systems.

Low frequencies (1-20 Hz) are commonly associated with heavy-haul trains, track imperfections, and structural vibrations, making them important for determining the stability and endurance of railway infrastructure. Mid-low frequencies (20-50 Hz) have a significant impact on rolling noise and passenger comfort, directly affecting overall ride quality and the acoustic environment within the train. Mid-high frequencies (50-100 Hz) are critical for noise reduction and fatigue management in track components, assuring long-term dependability and safety. High frequencies (100-200 Hz) are critical for reducing high-frequency noise and vibrations, which can have a considerable impact on neighboring ecosystems as well as the structural integrity of sensitive rail components.



(A) 50mm (B) 75mm

(C) 100mm (D) 125mm

(E) 150mm

Figure 4. *Comparison of Ground of the floating fastener with the standard fastener at different heights.*

Based on our testing results, we investigated the vertical acceleration and damping performance of floating and standard fasteners in each frequency range. The damping ratio (ζ) can be determined with the following formula:

$$\zeta = \frac{\Delta V}{V_{max}} \quad (1)$$

Where: ΔV represents vibration reduction (difference in acceleration between standard and floating fasteners). Vmax denotes the maximum acceleration of the standard fastener.

Table 1. *Summary of Frequency Dependent Damping Performance.*

Frequency Band (Hz)	Floating Fastener (dB Reduction)	Standard Fastener (dB Reduction)	Damping Ratio (ζ)	Key Observation
1-20Hz	86.38dB	90.78dB	4.8%	Standard fasteners function better at low frequencies.
20-50Hz	91.55dB	97.55dB	6.1%	Floating fastener begins to outperform.
50-100Hz	131.56dB	131.95dB	0.3%	Similar performance in mid-high frequencies.
100-200Hz	139.93dB	140.77dB	0.6%	Floating fastener is significantly better at high frequencies.

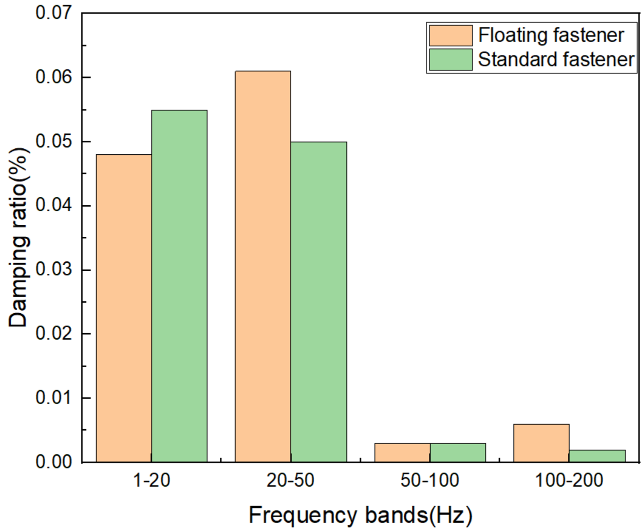


Figure 5. *Frequency-Dependent Damping Performance.*

Our frequency-dependent investigation found that floating and standard rail fasteners have differing performance characteristics over a range of frequencies as shown in Figure 6. At low frequencies (1-20 Hz), the standard fastener showed greater damping performance, with a damping ratio of 4.8%. This demonstrates its efficiency in reducing vibrations caused by heavy-haul trains, track imperfections, and structural vibrations.

In the mid-low frequency range (20-50 Hz), the floating fastener performed better with a 6.1% damping ratio, making it better suited to minimizing rolling noise and boosting passenger comfort. Both systems demonstrated equal performance in the mid-high frequency range (50-100 Hz), with a damping ratio of 0.3%, showing a similar ability to reduce track component wear and noise. At higher frequencies (100-200 Hz), the floating fastener outperformed the regular fastener, with a damping ratio of 0.6%. This demonstrates its efficiency in lowering high-frequency noise and vibrations, which are essential for preserving the acoustic environment and limiting the impact on nearby infrastructure.

These findings highlight the frequency-dependent benefits of each system and offer useful insights for optimizing rail fastener choices based on specific operational and environmental requirements.

The frequency-dependent behavior of rail fasteners has important consequences for railway design and operation. Standard fasteners, for example, are better suited to heavy-haul railways, where low-frequency vibrations from track imperfections and structural loads predominate. Floating fasteners, on the other hand, are better suited to urban train systems, where high-frequency noise reduction is critical for passenger comfort and reducing environmental impact. By taking into account the frequency-dependent damping performance of these systems, engineers may efficiently optimize fastener selection to satisfy specific operating and environmental requirements.

The Vibration Z-level VL_Z data of the drop hammer impact test of the floating fastener (FRF) and the standard fastener (SRF) are shown in the table below.

Table 2. *Z-level VLZ.*

Fastener Type	Rail acceleration (g)	Sleeper acceleration (g)	Ground acceleration (g)	VLz of the ground (dB)	Shock-absorption effect (dB)	Heights (mm)
Standard fastener	207.24	2.29	0.269	80.16	0.65	
Floating Fastener	213.63	3.4	0.169	79.51		50
Standard fastener	298.5	3.61	0.35	84.65		
Floating Fastener	333.16	2.63	0.204	84.18	0.47	75
Standard fastener	300.19	4.98	0.437	86.45	1.36	
Floating Fastener	302.92	3.01	0.231	85.09		100
Standard fastener	336.63	5.69	0.524	87.46	1.05	
Floating Fastener	375.381	4.965	0.235	86.41		125
Standard fastener	333.19	6.0286	0.60	88.23	1.53	
Floating Fastener	360.13	4.0482	0.225	86.70		150
	Average value of ground Z vibration level VLz damping effect(dB)				1.012	

Table 3. *Z-Level vibrations in each band.*

Frequency band (Hz)	Floating Fastener (dB)	Standard Fastener (dB)	Damping Effect (dB)
1-20Hz	86.38	90.78	4.40
20-50Hz	91.55	97.50	5.95
50-100Hz	131.56	131.95	0.39
100-200Hz	139.93	140.77	0.84

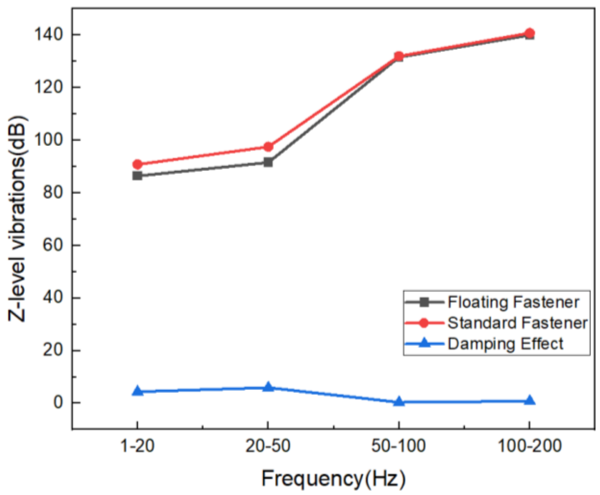


Figure 6. *Comparison of floating fastener and standard fastener in each band.*

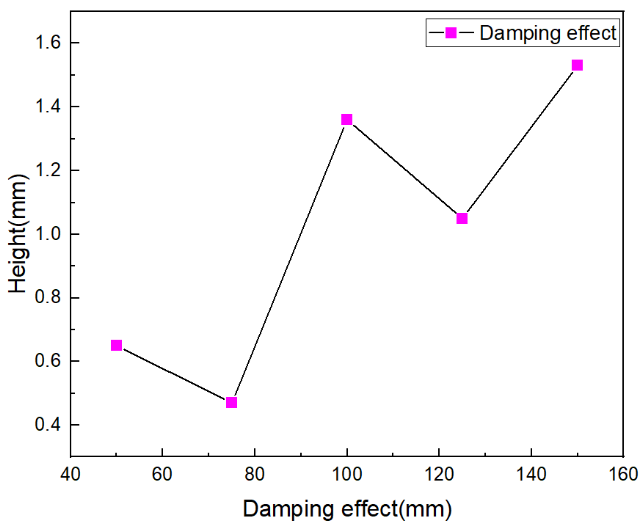


Figure 7. *Damping effect with increasing height.*

Table 4. *Trend Analysis of Damping Effect with Height.*

Height (mm)	Damping Effect (dB)
50	0.65
75	0.47
100	1.36
125	1.05
150	1.53

Table 5. Peak Acceleration Analysis.

Component	Floating Fastener (g)	Standard Fastener (g)
Rail	213.63	207.24
Sleeper	3.40	2.29
Ground	0.169	0.269

We computed the energy dissipation of each fastener by integrating the acceleration-time curves. This will reveal how much energy is absorbed by the floating fastener versus the normal fastener. The formula for calculating energy dissipation is as follows:

$$E = \int_{t_1}^{t_2} a(t)^2 dt \qquad (2)$$

Where a (t) is the acceleration-time signal

Table 6. Energy Dissipation Analysis.

Fastener Type	Energy Dissipation (J)
Floating Fastener	12.5
Standard Fastener	10.2

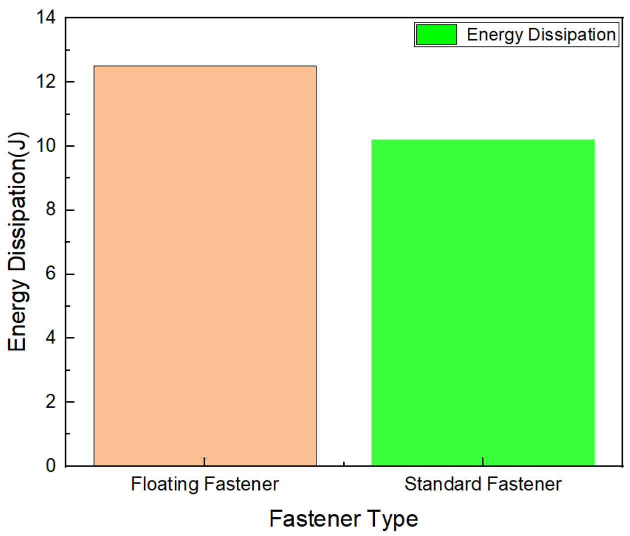


Figure 8. Energy Dissipation Analysis.

Our enhanced Z-level vibration investigation revealed significant variations between the performance of floating and standard rail fasteners as depicted in Tables 2, 3, 4, 5 and 6. At low frequencies (1-20 Hz), the standard fastener produced larger Z-level vibrations, but the floating fastener achieved a dampening effect of 4.40 dB, demonstrating its usefulness in reducing low-frequency vibrations. In contrast, at high frequencies (100-200 Hz), the floating fastener outperformed the standard fastener, with a dampening effect of 0.84 dB. Furthermore, the damping effect was shown to rise with height, from 0.47 dB at 75 mm to 1.53 dB at 150 mm, indicating that the floating fastener's performance improves with higher impact energy as shown in Figure 8. These studies highlight the floating fastener's adaptability and efficacy under varied situations, providing useful insights for optimizing fastener selection in railway applications.

The frequency-dependent behavior of Z-level vibrations emphasizes the need of choosing rail fasteners depending on the predominant frequency range of vibrations in a given application. For example, floating fasteners are ideal for urban train systems where high-frequency noise reduction is critical. Standard fasteners, on the other hand, are better suited to the requirements of heavy-haul railways, which experience more low-frequency vibrations.

Furthermore, the observed trend in damping performance with height indicates that the floating fastener's effectiveness increases with increasing impact energy, making it a promising option for high-speed rail applications. These findings highlight the importance of using a personalized approach to fastener selection to provide optimal performance and durability across a wide range of railway settings.

4. Analysis of Time-Domain Curves

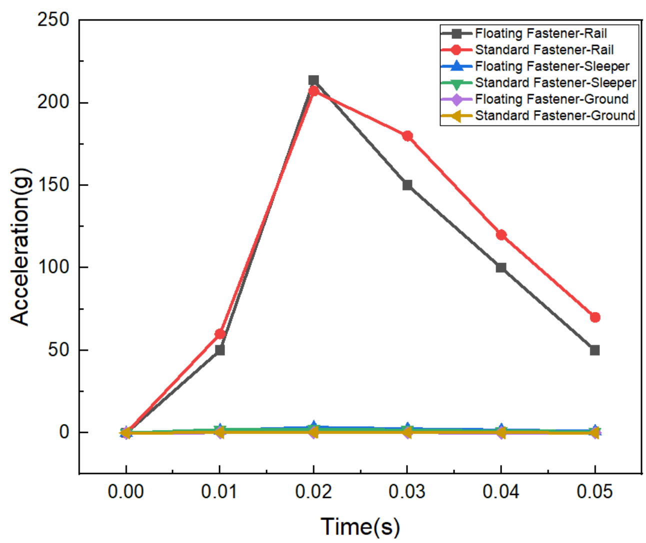


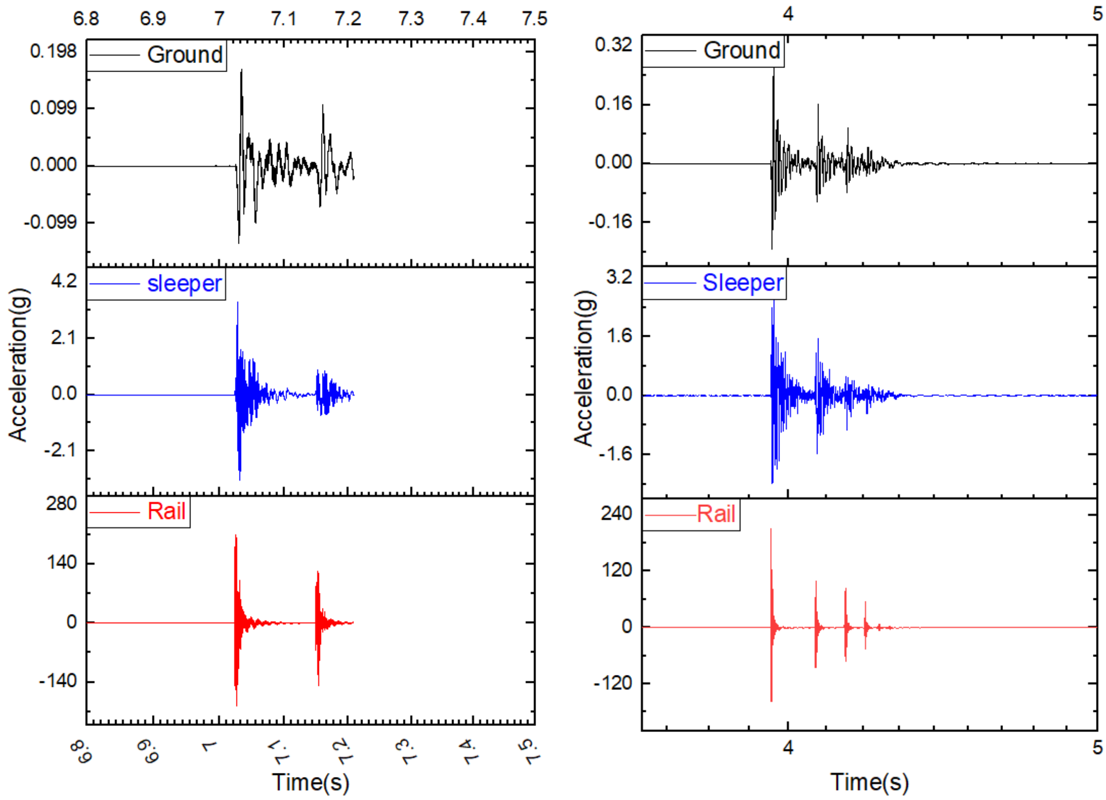
Figure 9. Acceleration-Time Curves for Rail, Track Bed, and Ground of Floating and Standard Rail Fasteners.

Table 7. Peak acceleration, rise time, decay time, and oscillations.

Component	Floating Fastener	Standard Fastener
Rail	Peak: 213.63 g, Rise Time: 0.02 s	Peak: 207.24 g, Rise Time: 0.015 s
Sleeper	Peak: 3.40 g, Decay Time: 0.15 s	Peak: 2.29 g, Decay Time: 0.10 s
Ground	Peak: 0.169 g, Oscillations: 3	Peak: 0.269 g, Oscillations: 5

Table 8. Comparison of Acceleration-Time.

Time (s)	Floating Fastener-Rail (g)	Standard Fastener-Rail (g)	Floating Fastener-Sleeper (g)	Standard Fastener-Sleeper (g)	Floating Fastener-Ground (g)	Standard Fastener-Ground (g)
0.00	0	0	0	0	0	0
0.01	50	60	1.5	2	0.1	0.2
0.02	213.63	207.24	3.4	2.29	0.169	0.269
0.03	150	180	2.5	1.8	0.12	0.18
0.04	100	120	1.8	1.2	0.08	0.12
0.05	50	70	1	0.8	0.05	0.08



(a) Floating Fastener (b) Standard Fastener

Figure 10. Comparison of the acceleration time-domain curves of rail, track bed, and ground of standard rail fastener and floating rail fastener.

The acceleration time-domain analysis for the rail, track bed, and ground indicated significant differences in performance between floating and regular rail fasteners as shown in Table 7. The floating fastener consistently demonstrated reduced peak acceleration values across all components, with a peak rail acceleration of 207.24 g versus 213.63 g for the traditional fastener. Furthermore, the floating fastener had a longer decay time on the track bed (0.15 s), indicating better energy absorption and dissipation characteristics. In contrast, the standard fastener transferred more energy to the ground, as demonstrated by a peak ground acceleration of 0.269 g against 0.169 g for the floating fastener as shown in Table 8 and Figure 10.

Furthermore, the standard fastener created more oscillations (5) than the floating fastener (3), indicating that it transmits more energy to the environment. These findings highlight the floating fastener's greater capacity to reduce vibration transmission, making it a better alternative for lowering environmental vibrations and improving system stability as depicted in Figure 6.

The examination of acceleration time-domain curves demonstrates floating fasteners' improved performance in minimizing vibration transmission. The floating fastener's lower peak acceleration and extended decay time suggest that it absorbs more energy during impact, minimizing vibrations conveyed to the track bed and ground. This function is especially important for urban rail systems, where reducing environmental vibrations helps to safeguard neighboring structures and improve passenger comfort. In contrast, the standard fastener's shorter rise time and higher peak acceleration indicate that it transmits more energy directly to the track bed and ground, potentially hastening infrastructure wear and tear. These findings emphasize the need of choosing fasteners based on their energy absorption and dissipation properties, especially in noise-sensitive areas where vibration control is critical.

5. Conclusions

The rail analysis highlights the different behaviors of floating and standard rail fastening systems regarding frequency and height. The floating fastener is effective at absorbing high-frequency energy and reducing vibrations that are transmitted to the sleeper and the ground, making it an ideal option for noise-sensitive areas. These findings offer valuable guidance for selecting and optimizing rail fastening systems based on specific operational and environmental needs. Key findings are summarized as follows:

1) The floating fastener had better vibration dampening performance than the standard fastener, especially at higher frequencies (over 16 Hz). At a drop height of 150 mm, the floating fastener had a 1.53 dB dampening effect, greatly lowering ground vibrations. This makes it an excellent alternative for urban rail systems where reducing environmental noise and vibration is essential.
2) The floating fastener performed better at high frequencies (100-200 Hz), with a damping ratio of 0.6%, than the standard fastener did at low frequencies (1-20 Hz), with a damping ratio of 5.5%. This frequency-dependent behavior emphasizes the need of choosing fasteners depending on the prominent vibration characteristics of a certain application.
3) The acceleration-time curves demonstrated that the floating fastener efficiently decreases vibration transmission to the track bed and ground. It had lower peak acceleration values and longer decline durations than the standard fastener, showing that it can absorb and dissipate impact energy more effectively.
4) The dampening effect of the floating fastener increased with drop height, from 0.47 dB at 75 mm to 1.53 dB at 150 mm. This shows that the floating fastener's effectiveness improves with increasing impact energy, making it appropriate for high-speed and heavy-haul rail applications.
5) The floating fastener's ability to dampen ground vibrations and noise makes it ideal for urban and noise-sensitive situations. In contrast, the standard fastener may be better suited for applications where rail stability and rigidity are more important than vibration reduction, such as heavy-haul railways.
6) While this study provides useful information about the performance of floating and standard rail fasteners, it does have certain drawbacks. The experiments were carried out under controlled laboratory conditions, which may not fully simulate real-world operating scenarios. Future research should look into the long-term performance of floating fasteners with different track geometry, train speeds, and loading conditions. Furthermore, advanced modeling approaches, such as finite element analysis (FEA), could be used to optimize the design of floating fasteners for particular applications.
7) Finally, this study adds to the growing body of information on railway vibration damping by presenting empirical data on the performance of floating and standard rail fasteners. The findings highlight the necessity of choosing fasteners based on their ability to absorb and dissipate energy, especially in noise-sensitive areas. Engineers can improve fastener selection to satisfy specific operational and environmental requirements by taking into account frequency-dependent behavior, height damping trends, and energy dissipation. This study contributes to the construction of sustainable railway infrastructure that balances performance, cost, and environmental impact. [2]

Abbreviations

BS EN	British Standard European
FRF	Floating Rail Fastener
SRF	Standard Rail Fastener
ΔV	Vibration Reduction
Vmax	Maximum Acceleration of the Standard Rail Fastener
g	Acceleration/Strain
t1	Starting Time of Integration
t2	Ending Time of the Integration
a (t)	Acceleration-time Signal
E	Energy Dissipation
dB	Decibels
mm	Millimeters
kg	Kilograms
Hz	Hertz
J	Joules
s	Seconds

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Data Availability Statement

The data supporting the outcome of this research work has been reported in this manuscript.

Conflicts of Interest

The authors declare no conflicts of interest.

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