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HUMAN ANNOYANCE FROM RAILWAY TRAFFIC-INDUCED GROUND VIBRATIONS IN URBAN: A REVIEW

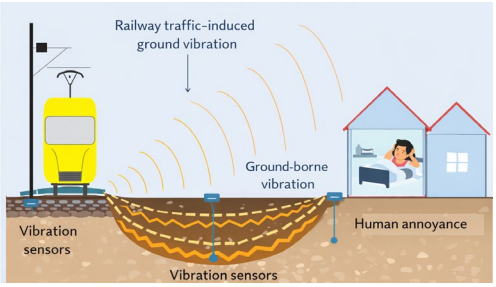
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Graphical abstract



Abstract

The increasing focus on urbanization and transportation networks has raised concerns about the impact of ground-borne vibrations from railway traffic on human well-being. These vibrations, transmitted through the ground into nearby buildings, can cause annoyance, discomfort, and potential health issues. While past research explored vibration fundamentals and progress, this review addresses gaps in understanding their psychological and social impacts on urban populations. The review examines the correlation between factors influencing ground-borne vibration (GBV) including vibration intensity, frequency, exposure duration, soil conditions, and buildings characteristics and human annoyance, as well as the associated psychological and social impacts on urban communities. Findings highlight that low-frequency vibrations are strongly associated with higher annoyance levels. Proximity to railway lines and older building infrastructure intensified effects. Individual sensitivity varied, with some reporting discomfort even at lower vibration levels. The review also emphasizes the importance of considering residents' subjective experiences when assessing impact. Ultimately, this review concludes that railway-induced vibrations significantly affect quality of life in urban areas, underscoring the need for effective mitigation strategies and stricter regulatory frameworks.

***Keywords*:** Vibration, Annoyance, Railway Traffic, Psychological Behaviour

Abstrak

Peningkatan tumpuan terhadap pembandaran dan rangkaian pengangkutan telah menimbulkan kebimbangan mengenai kesan getaran bawaan tanah akibat trafik kereta api terhadap kesejahteraan manusia. Getaran ini, yang dipindahkan melalui tanah ke dalam bangunan berdekatan, boleh menyebabkan gangguan, ketidakselesaan, dan potensi masalah kesihatan. Walaupun penyelidikan terdahulu telah meneroka asas dan perkembangan getaran, ulasan ini menangani jurang pengetahuan berkaitan kesan psikologi dan sosialnya terhadap populasi bandar.Ulasan ini meneliti hubungan antara faktor-faktor yang mempengaruhi getaran bawaan tanah (GBV), termasuk keamatan getaran, frekuensi, tempoh

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pendedahan, keadaan tanah, dan ciri-ciri bangunan, dengan gangguan yang dialami manusia, serta kesan psikologi dan sosial yang berkaitan dalam komuniti bandar. Dapatan kajian menunjukkan bahawa getaran frekuensi rendah mempunyai kaitan yang kuat dengan tahap gangguan yang lebih tinggi. Kedekatan dengan laluan kereta api dan infrastruktur bangunan yang lebih lama meningkatkan lagi kesan tersebut. Kepekaan individu didapati berbeza-beza, dengan sesetengah individu melaporkan ketidakselesaan walaupun pada tahap getaran yang lebih rendah.Ulasan ini juga menekankan kepentingan mengambil kira pengalaman subjektif penduduk dalam menilai impak getaran. Secara keseluruhannya, ulasan ini menyimpulkan bahawa getaran akibat kereta api memberi kesan yang signifikan terhadap kualiti hidup di kawasan bandar, sekali gus menekankan keperluan kepada strategi mitigasi yang berkesan serta rangka kerja peraturan yang lebih ketat.

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1.0 INTRODUCTION

The rapid growth of urban centres and increasing demand for efficient transportation have driven the expansion of railway systems as a crucial mode of transit. Railways play a vital role in modern infrastructure, facilitating the movement of people and goods in densely populated regions. However, this study aims to critically review the psychological, behavioural, and physiological impacts of railway-induced ground-borne vibrations (GBV) on residents in urban communities. The novel contribution of this review lies in its interdisciplinary approach linking civil engineering vibration dynamics with human health and behavioural psychology, which remain underrepresented in global literature. By synthesizing studies from engineering, environmental psychology, and public health, this review offers a holistic framework to understand GBV as a multidimensional urban problem, identifying key variables and proposing integrative mitigation strategies.

The theoretical lens of this review is grounded in environmental stress theory and exposure-response modelling, which describe how persistent environmental stimuli (like vibration) translate into psychological stress and health outcomes [1]. Although past studies have addressed vibration mechanics and structural impacts [2,3], few have critically assessed the psychosocial dimensions of GBV or contextualized these findings within high-density urban environments. Furthermore, existing models tend to overlook the cumulative effects of vibration on mental health, daily behaviour, and urban liveability, particularly under chronic exposure conditions. This review examines the relationship between GBV characteristics, including vibration intensity, frequency, exposure duration, soil conditions, and building characteristics, and human annoyance in urban environments, with particular emphasis on the associated psychological and social impacts. It further explores how long-term exposure to GBV shapes community behaviour and psychology. Filling these gaps is essential to inform national mitigation policies, guide railway expansion planning, and reduce public health burdens in rapidly urbanizing nations.

Urbanization has led to the densification of residential and commercial developments near railway corridors, intensifying the effects of GBV on buildings and human comfort. These vibrations, generated by trains, propagate through the soil and interact with urban infrastructure, potentially amplifying vibration levels due to complex soil-structure interactions. As railway networks extend into densely populated urban areas, GBV is increasingly recognized as a pressing environmental issue, affecting not only technical infrastructure but also the well-being of nearby residents, particularly during quiet periods such as nighttime.

Railway transportation constitutes a fundamental component of urban mobility systems in many countries, particularly in high-density urban nations such as Malaysia. In rapidly urbanizing regions like the Klang Valley, railway infrastructure provides a reliable, efficient, and high-capacity mode of public transport, supporting both daily commuting and long-distance travel [4]. Malaysia's rail network comprises commuter rail services, the Express Rail Link (ERL), Light Rapid Transit (LRT), commuter train, and Mass Rapid Transit (MRT) systems, operating across elevated, ground-level, and underground alignments. The continued expansion of these systems contributes to sustainable urban mobility and reduces reliance on private vehicles [5–7].

The Klang Valley is one of Malaysia's most densely populated and economically dynamic regions. In response to rapid urbanisation and increasing travel demand, the regional railway network has expanded significantly. As illustrated in Figure 1, all the trains system extensions have enhanced connectivity between urban centres and surrounding suburban areas, while government initiatives continue to promote rail-based transport as a strategy to alleviate road congestion. Beyond the Klang Valley, national railway development plans aim to

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strengthen connectivity across multiple states in Malaysia [8].

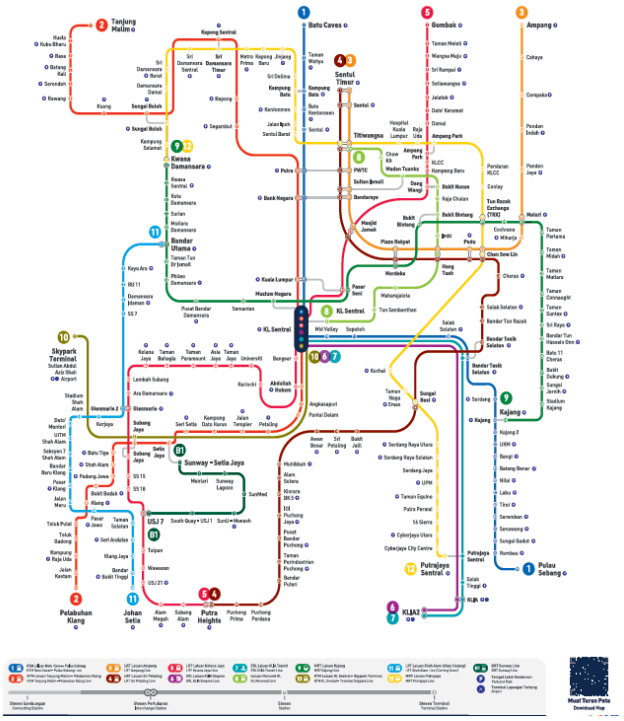


Figure 1 Klang Valley Integrated Transit Map [8]

GBV is a critical factor affecting urban residents, contributing to sleep disturbances, discomfort, and reduced quality of life [9]. As railway lines pass through densely populated areas, concerns over GBV-induced human annoyance have grown, highlighting the need for effective mitigation strategies.A study by Morihara et al. (2021) examined the effects of noise and vibrations caused by the Hokuriku Shinkansen railway on residents' living environments through a socio-acoustic survey conducted one year after the railway's opening. Vibration exposure levels were measured at outdoor points closest to the noise source side of the houses. Of the 1,980 people contacted, 1,022 provided valid responses. The study found that areas without prior railway exposure experienced higher levels of noise annoyance and daily disruptions. This underscores the importance of considering pre-existing railway infrastructure when establishing guidelines for high-speed rail systems.

The urgency of addressing GBV is emphasized by its impact on residents' well-being, particularly during sensitive periods like nighttime. Without effective mitigation, GBV-related disturbances will continue to affect urban communities. While awareness of this issue is growing, research gaps remain regarding the direct correlation between vibration characteristics, human perception, and annoyance levels. Factors such as individual sensitivity, building characteristics, and environmental conditions like soil composition remain underexplored.

In this case, Peris et al. (2016) examined how railway vibrations at different times of the day can significantly disrupt residents living near railway tracks. Data from case studies, which included face-to-face interviews and internal vibration measurements (N = 755), revealed that vibration-induced annoyance varies with the time of day. Their findings indicate that exposure-response relationships should incorporate time-of-day weightings, as nighttime disturbances tend to be more pronounced. Prolonged exposure to GBV can lead to increased stress levels and potential mental health impacts, highlighting the need for further research into its long-term effects. Railway-induced GBV can lead to various negative effects on individuals, including sleep disturbances, interference with daily activities, and a decline in overall quality of life especially in utban communities.

The expansion of railway systems has introduced not only improved urban mobility, but also significant challenges related to human annoyance and discomfort. Recent studies have identified GBV as a source of health concerns, economic losses, building damage, and social disruption. Vasheghani et al. (2022) emphasized the need for stronger legal frameworks to address public dissatisfaction with railway-induced vibrations. Legal reforms and increased public awareness are essential for mitigating the negative effects of GBV and improving the quality of life for affected communities.

To minimize GBV's impact, targeted interventions such as land-use planning, green buffer zones, and public education initiatives should be considered. Locating commercial spaces or green areas near railway lines instead of residential developments can help mitigate vibration exposure. Additionally, educating communities about GBV and its effects can empower residents to advocate for mitigation measures.

Thus, railway-induced GBV is a growing concern in high density urban communities with significant implications for human annoyance and quality of life. Addressing this issue requires a combination of research, policy implementation, and urban planning strategies. This study aims to explore the effects of railway-induced GBV on urban communities and provide insights into mitigation strategies. By bridging existing research gaps and establishing comprehensive guidelines, this study can contribute to the future of sustainable urban well-being.

2.0 GROUND BORNE VIBRATION

GBV refers to the transmission of mechanical vibrations from various vehicles to the ground and surrounding structures. These vibrations can have significant implications for both the infrastructure and

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the environment, leading to concerns about structural damage, human discomfort, and potential long-term effects on health. Table 1 lists the frequency of the vibration induced by different vehicles with vibration from the vehicles.

Table 1 Frequency of vibration induced by different vehicles

Types of vehicles	Frequency inside vehicles	Sources of vibration caused inside vehicles (Hz)	Frequency outside vehicle (Hz)	Ref
Train	Train's structure	1-100	0-150	[13–16]
Bus	Engine	25-35	9-27	[14,17,18]
Truck	Suspension system Response of the tires Response of the truck's structures	3-4 15-20 40-55	10-35	[19–21]
Car	Shock absorber Suspension system Engine Car body	Peak value 55 50-200 100 20-30	3-30	[22,23]
Motorcycles	Engine combustion process Handler bar Seat	100-250 12-16 9-20	No data available	[20,24]

GBV is commonly measured using peak particle velocity (PPV), vibration in decibels (VdB), and vibration dose value (VDV), with VdB being the most frequently used metric in 51% of reports and VDV referenced in 27%. Numerical modeling methods, such as finite element and boundary element approaches, are used for sensitivity studies and predictive analyses but require precise input parameters, often obtained through in-situ tests. Alternatively, physical transfer function tests, including in-situ drop-weight experiments, provide a cost-effective way to characterize vibration response but are limited to specific measurement locations. While numerical models offer broader predictive capabilities, transfer function methods are preferred for commercial assessments due to their practicality and efficiency.

Vibration within the railway system primarily originates from the dynamic interaction between the wheel and rail surfaces. The resulting elastic waves generated by this interaction propagate through the track and bridge infrastructure, ultimately leading to vibrations in the surrounding environment [25]. Vibration is produced at the contact between the wheel and rail, as seen in Figure 2. The movement of the wheel along the rail results in the application of consistent loads on the axle, whereas the presence of unevenness in the wheel/rail interface induces dynamic forces that lead to vibrations in both the track and the underlying soil [26]. Vibration can be detected either through direct sensory experience or indirectly through the detection of reradiated noise. GBV gets transmitted into structures and can be sensed as either perceptible whole-body vibration or as low frequency noise. While it can also impact sensitive machinery, the magnitude is often insufficient to induce any structural or cosmetic harm to buildings.

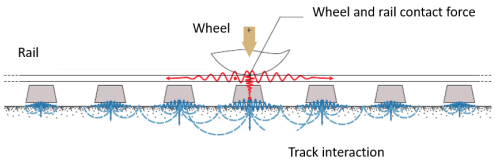


Figure 2 Vibration contact between wheel and rail [27].

Most recent literature on review articles narrowed have identified excessive GBV from railway activity as comprising three interrelated components: the source, the propagation path, and the receiver [28]. The occurrence of vibration resulting by railway activity may be understood as the propagation of waves through both buildings and the earth. The generation of energy can lead to adverse effects on those residing in proximity to railway tracks, causing discomfort as well as potentially causing interference with sensitive machinery [29]. Thus, this review article considers the results from GBV exhibits a higher level of complexity due to the presence of an inhomogeneous medium through which the vibrations propagate. This review work also displays considerable variations in its characteristics across different locations. The passage of the train in specific areas will likely generate a certain degree of response from the locals. Ultimately, the GBV induced by railway traffic on human annoyance is a complicated issue that significant attention from urban planners and policymakers. As railway network continues to expand it essential for creating urban environment in residential area for the effect of these vibrations

2.1 Mechanism Inducing GBV

The mechanisms that generate these vibrations the primary sources of GBV in the perspective of railway traffic include the interaction between trains and tracks and soil properties. On the other hand, the GBV employed from transmission of vibrations through the ground into buildings and other structures.

When focusing on trains move, especially heavy freight trains, dynamic forces are generated due to wheel-rail interactions [30]. These forces cause the

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track to deform slightly, resulting in vibrations that propagate through the ground. The study from Jing et al. (2021) exhibit that the design of the tracks, including their stiffness and alignment, can significantly influence the level of vibrations produced. For example, poorly maintained tracks or those with irregularities can lead to increased vibration amplitudes, which can be perceived as more disturbing by residents. Soil characteristics play a crucial role in how vibrations are transmitted from the source example the railway track to the surrounding environment [32]. Different soil types exhibit varying levels of stiffness and damping capabilities, affecting how vibrations propagate.

The propagation of GBV caused by trains may occur through numerous pathways inside the ground. The main approach is the direct transmission of energy from the train's wheels to the track, ultimately transferring it to the ground [33]. When the train's wheels contact the track, a vertical force is generated, which is then transmitted through the ground and may be perceived at locations far from the tracks. That vibration is frequently referred to as vertical GBV. Several types of vibration may be seen in railway systems, including track-induced vibration, rolling stock-induced vibration, and propulsion system-induced vibration. Track-induced vibration refers to a specific kind of vibration that arises due to the dynamic interaction between the wheels of a train and the track on which it operates. The transmission of vibrations may occur through the track bed, then propagating onto the surrounding ground, so inducing vibrations in nearby areas as shown in Figure 3. Various factors might potentially contribute to the occurrence of track-induced vibration. These factors include the track, such as ballasted or slab track as well as the state of the track, which can range from smooth to rough [34].

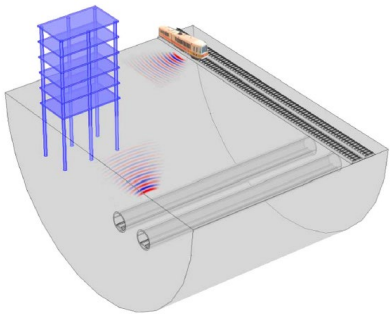


Figure 3 GBV from the railway track [35].

2.2 Factor influencing GBV

GBV have emerged as a significant concern in urban environments, particularly in areas near railway lines near urban communities. These vibrations can be influenced by various factors, including the properties of soil, type and speed of the trains, distance from the receiver, the propagation waves through receiver and the geological characteristics of the surrounding.

The properties of the soil play a significant role in how vibrations are generated and transmitted. The type of soil through which a railway system passes has a substantial impact on GBV. Different types of soil have varying stiffness, damping, and transmission properties that affect the interaction between the train and the ground [36]. This interaction, in turn, influences the generation and transmission of vibrations.

For instance, soft soils tend to amplify vibrations, leading to greater disturbance in nearby buildings. A study conducted in Klang, Malaysia found that urban areas with softer soil types experienced significantly higher levels of GBV compared to those built on firmer substrates [37].This is particularly relevant in Klang, Malaysia where urban development has led to significant changes in soil composition due to construction activities. The structural characteristics of those buildings can further influence the level of annoyance experienced by residents. Specific frequencies of vibrations can resonate with the natural frequencies of structures, leading to amplified vibrations within homes. For instance, residential buildings constructed with lightweight materials may resonate more strongly with low-frequency vibrations, escalate the perceived annoyance among occupants [38].To ensure minimal interference GBV, suitable types of soil with proper maintenance of track attributes reduced the GBV that affect annoyance experienced by residents especially living near railway lines.

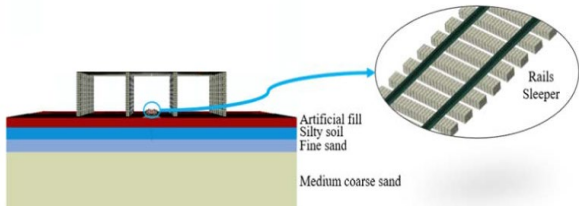


Figure 4 Soil layer railway track[39].

The damping characteristics of soil describe its ability to absorb and dissipate vibrational energy, thereby controlling the attenuation of GBV. Soils with higher damping capacity are generally more effective in reducing vibration amplitudes. In practice, the presence of layered soil profiles, as illustrated in Figure 4, further influences vibration transmission, as contrasts in stiffness and density between layers can cause wave reflection and refraction, complicating vibration propagation paths[39]. In addition, groundwater conditions play a significant role: the presence of a shallow water table alters soil stiffness

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and damping behaviour[40], with saturated soils typically being less stiff and exhibiting different vibration transmission characteristics compared with dry or well-compacted soils [41].

Overall, soil properties strongly govern the propagation and attenuation of GBV, particularly in soft or clayey ground conditions. Soft, highly plastic clays with high moisture content tend to amplify low-frequency vibrations[42], whereas stiffer and denser soils, such as dry sands or gravels, provide greater natural damping and attenuate vibrations more rapidly[43].

All this behaviour is closely linked to fundamental geotechnical parameters such as shear-wave velocity, density, and undrained shear strength. Increasing moisture content raises damping ratios and enhances dissipation of high-frequency energy[44], but simultaneously reduces stiffness and shear-wave velocity, which can promote large low-frequency motions and even resonance when soil natural frequencies coincide with vibration sources[45]. Consequently, reliable prediction and mitigation of GBV require explicit consideration of soil type, stratification, moisture condition, and key mechanical properties, particularly in soft alluvial or coastal regions where vibration sensitivity is inherently high.

The speed of the train is another critical factor influencing GBV. High-speed trains traveling over poor soil conditions, especially when moving at or above the critical speed relative to the wave speed of the soil, generate high vibration amplitudes in both the track and surrounding soil. In Figure 5, the vertical acceleration in over-track buildings increases significantly with train speed, rising 8.56 times from 100 km/h to 300 km/h, showing a strong speed-vibration correlation [46]. Over-track buildings experience higher accelerations than near-track buildings due to direct exposure. At 200 km/h, Building A (over-track) has 87% higher acceleration than Building B and 135% higher than Building C. Vertical acceleration, driven by train-wheel interactions and GBV, is the dominant vibration component. This highlights the significant impact the dominant vibration component affecting buildings is vertical acceleration, primarily caused by the direct interaction between the train's wheels and the rails and the subsequent GBV that propagate through the soil and building foundations. These findings emphasize the need for vibration mitigation strategies, especially for structures built directly above railway lines.

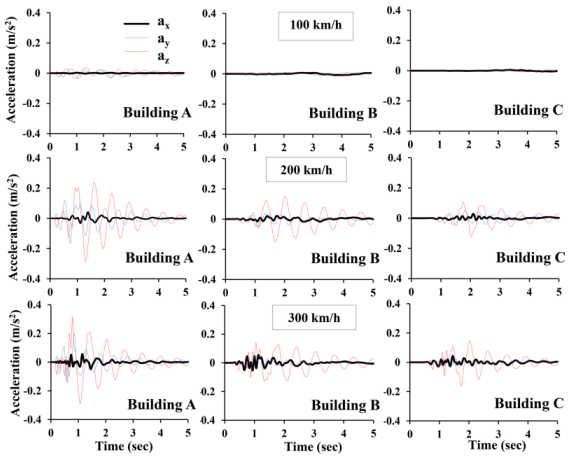


Figure 5 The vibration acceleration component affecting buildings on vertical acceleration [46].

Higher train speeds generate greater vibration energy, shifting dominant frequencies and increasing vibration amplitudes, particularly in harder soils where frequencies above 40 Hz become more pronounced. In study by Zou et al. (2020) softer soils amplify vibrations at lower frequencies (below 20 Hz) due to their lower stiffness and shear wave velocity. Faster trains also influence vibration energy dissipation, with softer soils experiencing prolonged vibration durations, while harder soils exhibit more high-frequency vibrations that attenuate faster.

The last component of the transmission stage in the propagation of ground vibrations caused by railway traffic is the receiver. The researcher has examined the reaction of buildings to vibrations, specifically investigating the impact of different foundation types on the transmission of vibrations from the ground to the structure, as well as the propagation of vibrations inside the building itself [47]. The vibrations generated by these sources have the potential to be enhanced, resulting in the vibration of walls and floors. Figure 6 illustrates the propagation of waves from the source to the receiver [26].

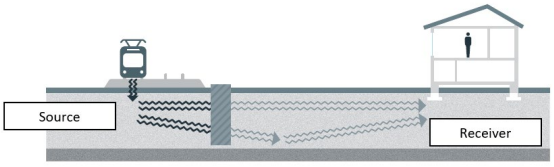


Figure 6 The propagation of waves from the source to the receiver [26].

Additionally, the perceived annoyance from these vibrations is closely tied to the distance between individuals and the vibration source. According to a study by Maclachlan et al. (2018) , individuals closer to the origin of the vibrations report higher levels of

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annoyance compared to those farther away. There is a positive correlation between proximity to the railway and the degree of annoyance, with those closest to the tracks being the most affected. A notable trend is observed at around 300 meters from the railway, where annoyance levels significantly increase, particularly with freight trains, which show this trend at 500 meters. This phenomenon can be attributed, at least in part, to the gradual reduction in vibration intensity as the distance from the source increases. Figure 7 illustrates how vibrations from the railway are transmitted towards nearby buildings, with distance playing a key role in moderating the vibration's strength and its impact on residents. The effects of transfer function by vibration in a building structure are influenced by many elements, including the attributes of the soil, the geometry of the building, the form of foundation, and the material composition of the structure. Furthermore, the effects of vibration on a building are also depend upon the configuration and positioning of furniture inside the structure [49]. The receiver comprises all propagation paths originating from outside of the building or residential area.

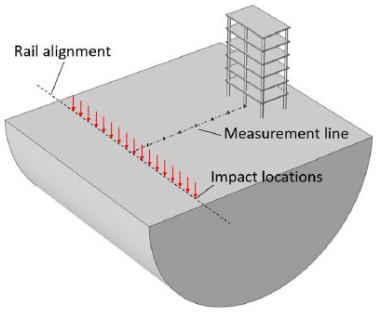


Figure 7 Effect of transfer function by vibration [35].

2.3 Model Validation with Field Measurements

Recent empirical and numerical studies have demonstrated the importance of reliable modelling approaches for predicting railway-induced GBV based on field measurements. In Malaysia, regression analyses consistently show that train speed and distance from the track are the dominant predictors of peak particle velocity (PPV) with different type of railway. Site-specific power-law models achieved strong correlations for commuter trains on soft ground ($R^2 \approx 0.86$)[43], while high-speed trains showed lower predictability ($R^2 \approx 0.68$) due to more complex soil–track–vehicle interactions and possible resonance effects at very high speeds. Nevertheless, speed and distance remained the primary controlling variables across train types. These empirical formulations are conceptually similar to classical blast vibration attenuation equations but adapted for continuous sources and modified to reflect soil conditions.

Study by Faizan [50], the numerical predictions of vertical and horizontal ground accelerations showed good agreement with measured free-field responses at varying distances from the track, demonstrating the reliability of simplified FEM approaches for real-world vibration prediction.This study provides strong evidence for model validation of railway-induced GBV through direct comparison between full-scale field measurements and simplified numerical modelling. In Europe, empirical field datasets are often combined with physics-based numerical models; for example, measurements from the VUZ Test Centre in Velim were used to calibrate and validate coupled track–soil models for soft clay over bedrock conditions [51].

Overall, these studies combining empirical regression with validated numerical modelling provides a robust framework for predicting railway-induced GBV.

2.4 Standard and Guideline on Vibration

Standards and guidelines on human annoyance related to GBV in railway systems are designed to assess and manage the potential discomfort experienced by individuals living or working near railways (Maclachlan et al., 2018). These regulations establish permissible vibration limits to mitigate adverse effects on human well-being. In this study, vibration velocity (mm/s) was used for comparison against the values outlined in Malaysian guidelines. Many countries reference the International Organization for Standardization (ISO) when developing their own vibration standards, leading to diverse approaches in evaluating human sensitivity to vibrations.

Table 2 illustrates international variations in vibration thresholds, summarizes various international and national standards for assessing vibration in residential environments. Vibration assessment guidelines vary across different national and international standards, preventing a universal approach due to differences in metrics, frequency weightings, and application focus. While ISO 2631-2 is widely referenced for human comfort evaluation, other standards like ANSI/ASA S2.71 (American), BS 6472-1 (British), and JIS C 1510 (Japan) adopt distinct methods, such as r.m.s. acceleration, vibration dose value (VDV), or running r.m.s. velocity. Some, like DIN 4150-2 (Germany) and NS 8176 (Norway), prioritize structural impact and long-term exposure. Additionally, Malaysia's DOE Guidelines (2020) not only focus on human perception but also structural and environmental impacts, working with railway authorities to minimize disturbances. This regulatory framework ensures a balance between efficient railway operations and environmental and public health protection, reinforcing DOE's crucial role in managing GBV in Malaysia. Establishing consistent guidelines will aid urban planners, engineers, and policymakers in designing infrastructure projects that

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minimize human annoyance while supporting sustainable urban development [52,53]. Since regulatory and environmental conditions differ across regions, no single standard is universally accepted, and practitioners must adopt the most relevant guideline based on local requirements and vibration sources.

Table 3 Guideline International Standard for Vibration

Standard/ Guideline	Metric/ Purpose	Special Considerations
ANSI/ASA S2.71 (American) [54]	r.m.s. frequency-weighted acceleration	Frequency range of 1 to 80 Hz, this standard gives guidance on the magnitude of vibration at which adverse human reactions
JIS C 1510 (Japan) [55]	Running r.m.s. frequency-weighted acceleration	Maximum vibration level with a time constant of 10 ms considering the effect of vibration duration when the vibration level is more than 70 dB by its 1/4 power.
BS 6472-1 (British Standards) [56]	Fourth power vibration dose	Used in railway and construction activity assessments
DIN 4150-2 (UK, Belgium and other European countries) [57]	Running r.m.s. velocity	Impact of vibrations on the residents.
NS 8176 (Norwegian) [58]	Running r.m.s. velocity	Vibration and transportation
Department of Environment Malaysia Guidelines (Malaysia) [59]	Vibration limits and control measures	Provides procedures and best practices for measurement, assessment, and mitigation of environmental vibrations.

By adhering to these standards and guidelines, railway operators and regulatory authorities can work together to ensure that GBV from railway systems do not unduly disrupt the quality of life for nearby communities. Continuous monitoring, assessment, and mitigation efforts help strike a balance between efficient transportation and community well-being.

3.0 HUMAN ANNOYANCE

Human annoyance is a psychological and physiological response to environmental stressors such as noise, vibration, odour, and overcrowding, which individuals perceive as intrusive or disruptive. This response is subjective, influenced by sensitivity, context, and exposure duration, and can lead to adverse health effects like stress, sleep disturbances, and cardiovascular issues. Environmental conditions, also known as ambient stressors, can significantly impact residential populations, with factors such as vibration and noise [1], visual and physical environments and odours [60] being widely studied. Among these, GBV from railway traffic is a growing concern in urban areas, as vibrations from passing trains contribute to human annoyance, leading to physical discomfort, psychological stress, and reduced quality of life. This connection has been acknowledged by organizations such as the UK Department for Environment, Food and Rural Affairs [61] and the European Commission Working Group on Health and Socio-Economic Aspects [48], highlighting the need for further research and mitigation strategies.

Table 4 Public perceptions regarding the presence of railway systems in their local area [62].

	Railway company eliminate vibration pollution by railway	Impact existence of railway on reducing beauty environment	Effect of vibration reducing quality life	Effect of vibration reducing price house	Possibility of moving from current resident
Mean	3.97	3.44	3.54	3.12	2.34
Standard Deviation	0.733	0.853	0.792	0.956	1.091
Very Low	5	0.8	1.3	8	18.4
Low	3.5	6.1	4.3	29	52.1
Average	14.6	56.9	44.1	36.2	13.6
High	60.9	20.5	39.6	25	9
Very High	20.5	15.4	10.6	8.8	6.9

Maljaee et al. (2022) explored the ongoing concerns regarding the welfare and quality of life of residents living near railway lines, focusing on the effects of railway noise and vibrations on resident dissatisfaction. The study, based on a questionnaire survey, gathered data that were analyzed using descriptive and inferential statistics. The results, measured on a 5-point Likert scale, indicated that a key concern for residents living close to railway lines is the urgent need for action by railway authorities to mitigate and control the disadvantages effects of noise and vibrations. Nearly 50% of the surveyed population resides more than 500 meters away from the railways, with over half of the respondents living in buildings that are between 5 to 20 years old. From the perspective of the residents, the most critical issue is the need for railway authorities to take decisive action to control noise pollution and mitigate the harmful effects of railway vibrations. In table 4, the results show that people are most concerned about whether railway companies are doing enough to reduce vibration pollution (mean: 3.97). Vibrations also impact quality of life (3.54) and

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environmental beauty (3.44), but people are less worried about house prices (3.12). The lowest concern is relocation (2.34), meaning most people don't find vibrations bad enough to move. Overall, vibrations do bother people, but they are more of an inconvenience than a major life-changing issue.

Vibrations are also perceived differently based on the time of day, with night-time vibrations being more disturbing due to their interference with sleep. Sleep disruption is one of the most reported impacts of GBV, as vibrations not only interrupt sleep cycles but also heighten the perception of annoyance. Morihara et. al. (2021) observed that residents who experienced sleep disruptions from night-time train traffic were more likely to report overall dissatisfaction with their living conditions and higher levels of daytime fatigue and irritability. This psychological toll, compounded by the lack of restful sleep, contributes significantly to human annoyance.

In addition to psychological stress, the physical discomfort caused by GBV is another critical factor contributing to human annoyance. Continuous or intense vibrations can cause structural reverberations in buildings, leading to the shaking of walls, windows, and furniture, which exacerbates the feeling of discomfort. He et al. (2023) conducted a study in high-rise apartment buildings near railway lines and found that residents on lower floors reported higher levels of vibration-related discomfort than those on upper floors. The physical shaking of homes and other structures can make residents feel as though their personal safety is at risk, further heightening feelings of annoyance. GBV induced by railway traffic gave impact on human annoyance in urban communities. This annoyance from a combination of factors, including the intensity and frequency of the vibrations, the psychological and physical discomforts in how individuals perceive and cope with them.

3.1 Human Psychology and Behaviour

Human psychology and behaviour play a critical role in how individuals and communities respond to environmental stressors such as GBV from railway traffic. These vibrations trigger various psychological reactions, ranging from mild irritation to heightened stress and anxiety, which, in turn, influence behavioural responses. The study of human annoyance induced by GBV in urban communities provides perception into how psychological factors interact with environmental conditions, shaping both individual coping mechanisms and collective behavioural patterns.

Communities often express concerns about the safety of living near railway tracks that experience GBV. Residents may worry about structural damage to their homes, the potential for accidents, or other safety issues. Figure 8 show the prolonged exposure to GBV may raise concerns about the health and well-being of community members. While research is ongoing, there is a growing awareness of potential links between vibrations and stress, sleep disturbance, and even cardiovascular health effects in vulnerable populations [64].

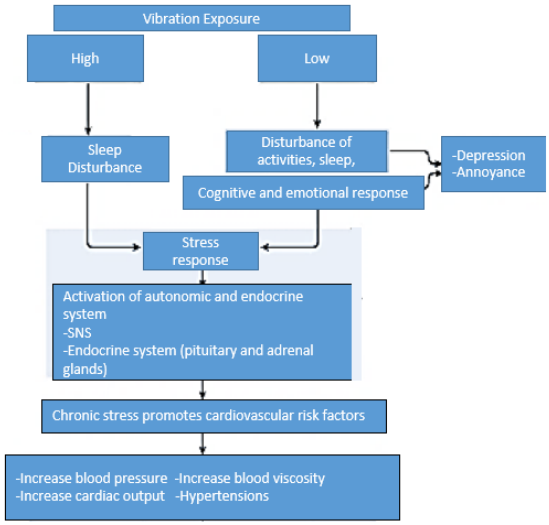


Figure 8 Prolonged exposure to GBV [65].

In response to GBV, some individuals exhibit cognitive adaptation, where they attempt to rationalize or minimize the impact of the vibrations on their daily lives. Cognitive adaptation can serve as a coping mechanism, allowing individuals to psychologically adjust to the disturbances. For instance, people may become less conscious of the vibrations over time or reframe the experience as a normal part of living near a railway. Qu et al. (2021) highlighted that in some urban communities, residents developed a sense of resignation or acceptance, particularly in areas where vibrations have been a long-standing issue.

Human behaviour in response to GBV can be both passive and active. On the passive side, residents may adjust their daily routines to minimize the disruptive effects of vibrations, such as using earplugs or moving to less affected rooms during train passages. Kou et al. (2021) found that individuals often alter their sleeping arrangements, moving to rooms farther from the railway to reduce night-time disturbances. These behavioural changes, while helpful in managing the immediate effects of GBV, are often temporary and do not address the root cause of the annoyance.

Active behavioural responses, on the other hand, involve efforts to mitigate the impact of vibrations on a larger scale. These responses can include advocating for infrastructural improvements, joining community action groups, or participating in public protests to demand governmental intervention. As highlighted by Bai et al. (2025) urban communities affected by GBV have increasingly organized to push

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for solutions such as noise barriers, vibration-dampening technologies, and better urban planning policies. In some cases, this collective behavior has led to meaningful change, though the success of such efforts depends on the socio-political context and the resources available to the community. GBV influence on human psychology and behaviour, especially in densely populated urban communities. While psychological reactions such as annoyance, stress, and anxiety are common, individuals and communities also develop cognitive and emotional adaptations to cope with the disturbances.

3.2 Factors that Contribute to Human Annoyance

Annoyance is influenced by a combination of environmental, psychological, and other factors, all of which contribute to how individuals perceive and react to vibrations in their surroundings. The intensity and frequency of vibrations are among the most significant physical factors contributing to human annoyance. Vibrations that are stronger, more frequent, or occur at irregular intervals tend to be perceived as more disruptive. Nering et al. (2020) observed that higher vibration intensities were linked to increased levels of annoyance in residents living near railway lines. The unpredictability of vibration occurrences, such as those happening at night or during irregular train schedules, can further escalate this annoyance, as they disrupt sleep and daily routines.

Additionally, lower frequency vibrations are more likely to be felt by residents in urban areas, especially those living in buildings with poor structural insulation. Ouakka et al. (2022) found that vibrations with low frequencies between 1 and 80 Hz were more likely to cause discomfort and annoyance, as they resonate with the human body and building structures, creating a more noticeable disturbance. Residents near railways exposed to such vibrations experience not only physical discomfort but also heightened psychological stress.

The duration and time of exposure to vibrations also significantly influence the level of human annoyance. Long-term or chronic exposure to GBV tends to increase sensitivity, with individuals becoming more irritated over time. According to Lazi et al. (2022) residents who have been exposed to vibrations for extended periods often report a cumulative effect, where even minor vibrations that were previously tolerable become sources of annoyance. This heightened sensitivity is particularly evident in older adults and individuals who spend a large amount of time at home.

Psychological factors, such as stress, anxiety, and perceived control over the environment, also influence how people respond to GBV. When individuals feel they have no control over the source of the disturbance, their level of annoyance increases. Lazi et al. (2021) found that individuals who perceived GBV as interruption reported higher levels of annoyance and psychological distress. This can amplify the emotional response to vibrations, leading to chronic stress and even resentment toward railway authorities. Human annoyance in response to GBV from railway traffic is a complex, influenced by various physical, psychological, and other factors. Vibration intensity, frequency, and duration are critical physical elements, while individual sensitivity, psychological conditions how residents perceive and react to these vibrations.

4.0 URBAN COMMUNITIES

Urban communities are increasingly shaped by the presence of infrastructure, particularly transportation systems like railways [72]. As cities expand, railway networks become essential for efficient transit, but they also introduce environmental challenges [73]. One of the less visible yet impactful consequences of rail traffic is GBV, which, though often imperceptible to the eye, can significantly affect the quality of life in nearby urban communities.

Railway tracks often pass through heavily populated areas, where high-rise buildings and apartment complexes dominate the landscape. A study by Wang et al. (2024) examined the relationship between residential density and vibration sensitivity, finding that residents in multi-story buildings close to railways are more likely to report feeling vibrations due to the structural amplification caused by taller buildings. This is particularly problematic in older urban areas, where buildings lack modern vibration dampening technologies. The vibrations disperse and reduce as they travel through the ground, resulting in lower levels of vibration at greater distances. The impact of GBV on receiver areas depends not only on the distance but also on the sensitivity of the receivers [75]. Highly sensitive structures or individuals may perceive and be affected by vibrations even at greater distances, while less sensitive ones may not.

Additionally, the proximity of residences to railway tracks influences the severity of vibration exposure. A field study by Tao et al. (2019) found that residents living nearby rail lines experienced significantly higher levels of discomfort and annoyance compared to those living farther away. This increased proximity leads to more intense vibrations, which disrupt daily activities, especially during night-time hours when external noise levels are low, and vibrations are more noticeable.

The psychological effects of railway-induced GBV on urban communities are reflective, particularly in terms of human annoyance and stress. Chronic exposure to vibrations has been shown to increase stress levels, leading to long-term health consequences. Barros and Lima (2024) conducted a survey of urban residents in cities with major rail lines and found that persistent vibrations contributed to a

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decline in mental well-being, with respondents reporting higher rates of anxiety, sleep disturbances, and irritability.

The social dynamics within urban communities also play a role in how vibrations are perceived. A study by Hanson et al. (2005) highlighted the importance of community perceptions of railway systems. Communities that view railway expansion as an imposition or that feel disconnected from the benefits of public transportation tend to report higher levels of annoyance from vibrations. Conversely, residents who recognize the value of rail transport for urban mobility may exhibit greater tolerance, even at similar vibration levels.

In conclusion, the impact of GBV induced by railway traffic on urban communities is substantial, particularly in residential areas. Residents in high-density urban areas, especially those living in multi-story structures, are more vulnerable to vibration-related discomfort and annoyance. Psychological effects, including heightened stress, anxiety, and sleep disturbances, further escalate the issue, particularly in communities that perceive railway expansion as intrusive. Thus, the integration of railway infrastructure in urban settings necessitates a balanced approach that considers both the need for efficient transit and the well-being of nearby residents.

4.1 Relationship Vibration with Community

These vibrations interfere the social of urban communities, influencing daily life and contributing to human annoyance. This explores how vibrations affect the day-to-day activities, social practices, and overall well-being of residents in urban communities. GBV can disrupt the rhythm of daily life in communities near railway lines. Studies show that persistent vibrations caused by passing trains interfere with essential activities, including sleep, work, and household tasks. For instance, Maljaee et al. (2022) found that residents exposed to vibrations reported difficulty concentrating on tasks such as studying or working from home. Addressing the dissatisfaction among residents in these districts requires close collaboration between the railway company and the government to council effectively tackle existing challenges. Furthermore, the construction quality of new buildings in these areas, which are among the city's most unfortunate, is a concern that demands stricter oversight and regulatory control. This was particularly notable during periods of high train traffic, when vibrations were most frequent. Sleep disruption, a common complaint among residents near railway lines, further complicates daily life.

These effects on daily life are more pronounced in high-density urban areas, where space constraints force homes, schools, and offices to be situated closer to railway tracks. Vibrations can interfere with the daily lives and work of residents. Activities related to railway operation such as manoeuvring, loading and unloading, truck movements, braking, squealing, and whistles are often called "non-conventional noise." Licitra et al. (2016) studied the differences between typical noise and recorded noise levels and explored the connection between railway vibration exposure and noise exposure. Dose-effect relationships for % highly annoyed and measured or simulated railway noise levels were calculated and compared. This research shows that the limitations of traditional noise mapping in railway epidemiological studies that focus only on standard transit noise, confirming that vibrations play an amplifying role in perceived disturbance. Thus, vibrations have impact on the daily lives of residents, influencing how they interact with their environment and each other. While some communities may adapt to the presence of GBV, the overall effects ranging from sleep disruption.

4.2 Community Behaviour due to Vibration

GBV caused by railway traffic can have a significant impact on urban communities, influencing not only physical structures but also shaping the behaviour of residents. These vibrations can disrupt daily life, social interactions, and community cohesion, leading to varied behavioural responses.

Residents in urban areas affected by railway-induced GBV tend to develop various coping mechanisms to manage the discomfort and disruptions caused by vibrations. These behaviours can range from physical adjustments in the home to psychological adaptation. According to Beben et al. (2022), many residents modify their living spaces by reinforcing windows, doors, or floors with vibration-dampening materials to reduce the perception of vibration within their homes. Some households go further by rearranging furniture or using heavy carpeting to minimize the effects of low-frequency vibrations on daily activities such as watching television or sleeping. Residents of a five-story building located approximately 150 meters from the railway have reported strong vibrations in the building caused by passing trains. These vibrations are sometimes so intense that they cause loose furniture in the rooms to move on their own [80].

In more extreme cases, persistent GBV can prompt relocation. According to a study by Zhu et al. (2020) a significant number of residents living near railway lines expressed a desire to move to less affected areas due to the cumulative stress caused by vibrations. While some residents may move within the same urban area, others choose to relocate entirely, seeking neighbourhoods farther from railway lines or in suburban areas where vibrations are less common. Vibrations from the operation of the Czech Republic's rail transit system have caused cracked bricks in some of the historical brick buildings near rail station, and even a collapsed old church due to such cracks [82]. The decision to relocate is often influenced by financial capacity, as higher-income

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individuals are more likely to have the means to move, leaving lower-income residents to bear the brunt of long-term exposure. The relationship between GBV and community behaviour in urban areas is complex, influencing everything from daily routines and social interactions to long-term decisions about relocation. Residents adapt to the presence of vibrations through a variety of coping mechanisms, but the discomfort and stress associated with prolonged exposure can lead to disrupt daily life and even relocation

5.0 CONCLUSION

This review confirms that GBV from railway traffic has a significant influence on human annoyance, psychological well-being, and overall quality of life, particularly in densely populated urban environments. The findings consistently show that low-frequency vibrations, proximity to railway lines, local soil conditions, and building characteristics and follow the standard and guideline play a critical role in amplifying residents' sensitivity and discomfort. Prolonged exposure to GBV is closely associated with sleep disturbance, elevated stress levels, and potential long-term mental health effects, with impacts being more pronounced during nighttime periods and in older or poorly insulated buildings. These results highlight that GBV is a critical yet often underestimated environmental issue accompanying rapid urban rail development.

Future research should therefore prioritise longitudinal health studies, expand investigations cross different urban and socio-cultural settings, and adopt interdisciplinary frameworks that integrate engineering, environmental psychology, and public health perspectives. In parallel, the use of advanced data-driven approaches, such as machine learning models, offers strong potential to improve prediction accuracy and support more effective mitigation strategies. A holistic and proactive approach combining regulation, engineering innovation, urban planning, and community participation will be essential to ensure that the benefits of rail infrastructure development are achieved without compromising public well-being and urban liveability.

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Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Data availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Ethics declaration

Formal ethical approval was not obtained for this study. However, the authors confirm that the research was conducted in accordance with established ethical principles and good research practices, with due consideration given to participant rights, informed consent, confidentiality, and responsible data handling.

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