Mitigation Of Railway Induced Ground-Borne Noise And Vibration

Rabih Alkhatib[*1], A. D. Lightstone[*1] and Sam Du[*1].
[1]Valcoustics Canada Ltd., Richmond Hill, Ontario, Canada.

1 Introduction

New surface and underground railway and rail transit lines are increasingly being introduced into urban areas as a result of intensification. Furthermore, new developments are being built with lighter construction materials and longer spans in close proximity to track alignments. This has led to more ground-borne noise and vibration being perceived inside buildings and increased potential for annoyance to the occupants. Vibrating walls and floors act like giant loudspeakers reradiating the acoustic energy as sound (noise). Low levels of vibration, even below the level of human perception can interfere with the operation of sensitive equipment found labs and high-tech facilities.

There are alternative methods to mitigate the impact of ground-borne noise and vibration from railway traffic which can be used individually or together: isolating the source, interrupting the vibration path and/or isolating the receiver.

The recommendations described hereafter arise from the past experience with railway ground-borne noise and vibration assessment and design for various projects.

2 Controlling vibration at the source

The dynamic interaction between the vehicle wheels and the rails is the source of ground-borne noise and vibration produced by railway traffic. Worn wheels, worn tracks, and special trackwork such as turnouts and switches will increase the level of interaction. Furthermore, some vehicle parameters such as the primary suspension system stiffness has a direct effect on the level of vibration being generated. Reduction of noise and vibration at source can be achieved by eliminating the running surface discontinuities, regular maintenance of the rail running surface, regular wheel re-profiling, and selecting the appropriate type of rail vehicle. Track vibration isolation can be achieved through the installation of resilient elements in the track superstructure.

2.1 System consideration

Rail grinding and replacement

Rail corrugation and irregularities developed over time cause increases in the ground-borne noise and vibration. Instituting a regular rail grinding and replacement program will prevent increase of noise and vibration associated with rail wear.

Wheel re-profiling and replacement

Hard braking can cause flat spots on the vehicle wheels which is termed “wheel flats”. Impacts from damaged wheels lead to significant increases in ground-borne noise and vibration. Grinding wheels with flat spots to round will eliminate the impacts caused by such wheels and reduce wheel/track dynamic interaction.

Vehicle specifications and maintenance

Unsprung weight (axles and wheels) and stiffness of primary suspension system are important factors in train induced vibration. Rail vehicles should be designed with low unsprung weight and soft primary suspension (vertical resonance frequency less than 15 Hz) to minimize dynamic forces generated by wheel/track interaction.

Location and design of special trackwork

Special trackwork such as turnouts and crossovers allow trains to switch from one track to another. This can be a major source of noise and vibration. When feasible, locating crossovers and turnouts away from sensitive land uses can be an effective mitigation measure. Another approach is to install spring-loaded frogs to eliminate gaps at crossovers and help reduce vibration levels.

2.2 Isolating the track

Vibration Isolation of the track has been effectively used to mitigate ground-borne noise and vibration. Increasing the track flexibility, by introducing resilient elements into the track system, reduces dynamic forces at the track support and thereby reduces the vibration propagating towards nearby buildings. Conventional railway track consists of sleepers (crossties) of wood imbedded in a bed of gravel (ballast), with the track fastened to the sleepers with steel spikes. Other systems use concrete slabs or segments in place of the sleepers.

Resilient rail fasteners

Resilient fasteners are used to fasten the rails to the sleepers or to the concrete track slabs. An elastomer pad which is part of the fastener system is inserted under the rail to reduce the vertical stiffness of the rail and therefore reduce the ground-borne vibration by as much as 4 to 8 dB at frequencies above 30 to 40 Hz. Highly resilient rail fasteners involve an elastomer component that mostly acts in shear under typical train loads.

Resilient sleepers/crossties

Resilient sleepers consist of concrete sleepers with rubber pads directly attached to the underside of the sleepers which

[*] solutions@valcoustics.com

sit on the ballast. The rails are fastened directly to the concrete sleepers using Direct Fixation (DF) fasteners. With relatively soft rubber pads between the sleepers and the ballast, it is possible to reduce the vibration by at least 5 to 10 dB at frequencies above 30 to 40 Hz

Booted sleepers/crossties

The booted sleeper systems consist of concrete sleepers encapsulated by elastic boots that are embedded into the concrete slab track. Booted sleepers act in similar manner as resilient sleepers but the design is integrated with a slab track. They are typically effective in reducing vibration by up to 10 dB in the frequency range of 20 to 30 Hz.

Ballast mats

Ballast mats are one of the most effective methods of reducing vibration transmission from ballasted track. It consists of relatively soft elastomer pad that is placed under the ballast. Ballast mats are less effective if placed directly on the soil or the sub-ballast. Depending on the soil properties, an asphalt or concrete layer under the ballast may be required. Ballast mats can provide between 10 to 15 dB vibration attenuation at frequencies above 25 to 30 Hz.

Tire-derived aggregate (TDA)

Made from shredded rubber tires, a typical TDA installation consists of 300 mm thickness of TDA (nominal 75 mm tire shreds or chips) wrapped with geotextile fabric placed on compacted subgrade and covered with 300 mm of sub-ballast and 300 mm of ballast directly beneath the sleepers. This type of mitigation can only be used on ballasted track. Field tests indicate that the vibration isolation effectiveness of TDA is midway between that of the most effective ballast mat and the floating slab track.

Floating slab track

A floating slab consist of a concrete slab supported on resilient elements such as discrete rubber pads, continuous elastomer mats, or steel coil springs. The track is attached to the concrete slab using Direct Fixation (DF) fasteners or embedded track. The resilient elements are supported on a concrete foundation. Floating slabs can be very effective at controlling ground-borne noise and vibration down to frequencies near 5 Hz. This type of track construction is costly and is typically used only where significant vibration mitigation is needed. Floating Slab Track can provide 15 to 20 dB vibration attenuation.

Design considerations

Isolating the track superstructure involves increasing the track compliance and therefore increasing the track deflection under the train load. Sudden change in track stiffness should be avoided as it lowers the fatigue life of the rails and degrades the ride quality of passengers. A transition zone with gradual stiffness change should be installed around mitigated section of the track.

Soil stratification and properties are important factors in determining the effectiveness of any of the above isolation methods. Calculation of the track stiffness with and without isolation should include an estimate of soil compliance.

The reduction in ground-borne vibration provided by any of these measures is heavily dependent on the frequency content of the vibration. Vibration measurements show various trains have different dominant frequencies. For any of the vibration isolation methods to work, the natural frequency of the isolation system should be well below the dominant frequency of vibration.

3 Controlling the transmission of vibration

Vibration waves diminish as they travel away from the source because of geometric spreading and soil material damping. Amplitude of vibration is inversely proportional to distance from railway tracks. Therefore, setback distance can be an effective mitigation measure against ground-borne noise and vibration. In new developments, locating the sensitive land use away from the alignment can reduce vibration impact.

For existing structures, ground vibration from rail operations can be reduced through the installation of trenches between the track and the building foundations in a similar manner to noise barriers. Trenches can be filled with materials such as foamed insulation board designed for below-grade use. Solid barriers can be constructed with sheet metal piles, rows of drilled shafts filled with either concrete or a mixture of soil and lime, or concrete poured into a trench. . Trenches typically are effective in reducing vibration from surface railway operations but have insignificant effect when it comes to vibration generated by subway lines.

4 Controlling vibration at the receiver

Vibration isolation of building foundation and footings using resilient elements, rubber bearing pads, or steel coil springs can be utilized to prevent vibration waves from being transmitted into building's interior. Although complicated, to avoid flanking, this approach can be particularly effective for buildings above transit lines or very close to subway or surface alignment. Vibration isolation of buildings is only practical for new development and unlikely to be used for existing buildings.

Alternatively, in non-residential buildings, the floor upon which vibration-sensitive equipment is located could be stiffened and isolated from the remainder of the building. Sensitive equipment could be locally isolated from the floor and building using special isolation equipment such as air spring isolation tables.

5 Conclusion

Controlling vibration at the source is considered the most effective method in mitigation of railway traffic induced ground-borne noise and vibration. However for new development near existing alignments, other methods should be considered such as building base isolation.