BUILDING BASE ISOLATION AS A MITIGATION MEASURE FOR RAILTRAFFIC NOISE

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1 INTRODUCTION

As cities are becoming denser on the one hand, and comfort levels with respect to noise & vibrations are set higher and higher on the other hand, mitigation measures for the noise & vibrations generated by rail traffic become more important, especially since rail traffic is going through a phase of expansion today. In case there is no or insufficient possibility to isolate the track infrastructure (= at the source), one can consider building base isolation (= at the receiver) as an interesting option, at least in case of new constructions. Cutting the future building at its base by means of rubbers or springs can indeed decrease the reradiated structural noise inside the building in a significant manner. For existing buildings located next to rail tracks, some possibilities will be explained as well, to reduce transmission of noise & vibrations.

2 RAIL TRAFFIC AS NOISE & VIBRATION SOURCE

2.1 Generation mechanism

Vibrations are generated through the wheel-rail contact as rolling stock passes by, since this contact is never totally smooth. There is the roughness of the wheel and the roughness of the rail on the one hand, and all kinds of discontinuities on the other hand (oil lubrication devices, rail welds, dust & stones, wearing out of the rail, squeeling, wearing out of the wheels, corrosion, etc.). Also the rail infrastructure can be of importance here: discontinuous setups (e.g. sleeper-based tracks) usually generate more noise & vibrations compared to continuous setups (e.g. slabtracks, where the rail is continuously supported in a uniform way along the track). Spots where the support resilience changes abruptly can also result in so-called “impedance jumps”, and should be eliminated as much as possible by introducing “transmission zones” with gradual adaptation of the support resilience. This is of main importance when parts of a trackline are being isolated with resilient materials such as ballast mats, undersleeper pads, railpads, floating trackbed systems, etc.
For passenger rail traffic (train, tram, metro) the excitation spectrum is situated mainly between 50 and 100Hz, often showing peaks at 63Hz, so this octave band is typically used as a focus when designing a building base isolation system. The intensity of the generated vibrations is depending on the speed of the rolling stock, and usually the vertical direction is the most important one; in the vicinity of stations and curbs however, it is recommended to consider the horizontal directions too.

2.2 Transmission paths

A part is radiated directly as airborne noise, travelling through the air and entering the building via the façade. This part can be reduced considerably by introducing a noise barrier or screen, or by improving the isolation capacity of the façade (e.g. by using special glazing). But an important part of the generated vibrations is introduced into the track infrastructure, travelling through the soil and entering nearby buildings via the foundations. This structure-borne noise component cannot be eliminated easily, resulting in the need for an efficient vibration isolation decoupling.

2.3 Reception modes

People working and living in buildings near rail traffic are disturbed mainly by the low-frequent noise which is radiated by the walls, floors and ceilings, as the threshold for this is approx. 0,01mm/s (vibration speed). The human ear roughly hears from 20Hz up to 20kHz, so 63Hz is still perceived quite well, although most normalization related to acoustics only starts from 100Hz. People will however hear the combination of the direct noise (airborne component) and indirect noise (structure-borne component). The direct noise component plays a role for the spaces facing the track, whereas the indirect noise component will dominate in the spaces at the backside of the building (the part not facing the track).
Vibration disturbance can become important when floor vibration levels are reached above the threshold of 0,1mm/s (so 10x higher than with noise), but this is rather seldom. Long-term vibrations lower than this threshold can however also lead to fatigue and cracks in a building, possibly causing esthetical problems (cracks in the façade or interior) or even stability problems (e.g. light steel structures which are bolted).

3 BUILDING BASE ISOLATION (FOR NEW CONSTRUCTIONS)

3.1 In general

Building base isolation is mainly used for 3 reasons: apart of noise and vibration isolation, it is namely also applied in case seismic isolation is required, or when the building is built on a weak or instable soil (especially of importance for asymmetrical constructions). In the latter situation helical springs are used. The big difference between a noise & vibration isolator and a seismic isolator is the fact that the first one is optimized for very small vertical vibrations, whereas the second one is designed to deal with (very) large horizontal displacements. The vertical stiffness of a seismic isolator must be high in order to maintain the vertical stability of the construction during an earthquake. So a very good seismic isolator is not meant to isolate noise & vibrations and vice versa, but a compromise can be found, i.e. isolators with a reasonable noise & vibration isolation efficiency, combined with a reasonable seismic isolation capacity.

3.2 Type of isolators

There are mainly two types of noise and vibration isolators in use: elastomers and (helical) springs. Springs are used for very critical situations, where very high levels of isolation are required (e.g. concert halls, studios, theaters,…), needing a cut off frequency below 5Hz (typically 3,5Hz). Elastomers are used for cut off frequencies above 5Hz (typically 10Hz). Types of elastomers used in building base isolation are: natural rubber, neoprene, corkelastomer and polyurethane. Elastomers are best applied in small pads, e.g. 100x100x50mm but can also be used in strips for linear supports (walls), and even in full surface mats, e.g. sandwiched between 2 foundations slabs. To reduce the transmission of shear wave energy in the suspended structure, it is however always best to keep the contact surface as small as possible, so by using elastomer pads with a high loading capacity like Kevlar-reinforced natural rubber. This also benefits on the cost (less elastomer material involved), and flexibility with respect to the loading scenario (possibility to correspond to any point load).

3.3 Precompression or not?

Precompression of the noise and vibration isolators is useful in case the concerning building is not capable to deal with large differential deflections during the construction process. Concrete structures with an asymmetrical shape installed on springs for instance, certainly require precompression in order to avoid excessive cracking during the construction phase.

Precompression of the isolators (typically at 80% of the dead load of the building) can be done in the factory, through specially designed steel boxes held by appropriate bolts. In some cases however, precompression is applied on site during the construction, like for light steel structures suspended by elastomers, requiring so-called “isolated fixations”. This is necessary to take up wind forces during construction.
An advantage of using precompressed boxes with springs or elastomers inside, is the fact that they can still be removed or substituted later on, at least when fully accessible. Removal is done by means of hydraulic jacks.

3.4 Layout considerations

The exact location of the vibration cut is chosen in function of the location of the reference room (this is the lowest space inside the building requiring isolation), and also in function of the building structure: what seems most practical: on top of the foundation piles / beams - under column feet – on top of column consoles – etc.? It is however always recommended to leave a “buffer” level between the vibration cut and the reference room, as the fraction of vibration energy which is transmitted over the vibration cut will be concentrated in the level right above. The design of the vibration isolation cut must be checked with respect to overloading, fire, water penetration and horizontal forces.

3.4.1. Risk for overloading

The capacity of the isolators (elastomers / springs) must be such that they resist mechanically without any problem to a load corresponding to 1,5 times the total load (= dead load DL + live load LL). The design of the isolators is however done on a load corresponding to the “Acoustical Design Load” (ADL = DL + (LL/3)), which is considered as a realistic and frequent loading scenario. In case the isolators can be overloaded during or after the construction, it should be checked what the effect is on the elasticity on the one hand, and if there’s no permanent shortcircuiting happening on the other hand (e.g. springs reaching coilbound). This can be avoided for instance by incorporating failsafes in steel or even concrete, into the vibration cut, together with the possibility to introduce jacking devices to lift up that part of the building for adding extra isolators when necessary. It needs to be stressed that steel springs have practically no creep (but can reach a state of “coilbound”), whereas all elastomer isolators must be checked with respect to creep (= long-term deflection), as there will be a certain loss of elasticity / isolation efficiency with time.

3.4.2. Fire risk

All elastomers used for noise and vibration isolation do burn. So it is important to evaluate the fire risk. In case the elastomer pads burn and melt, the building will deflect slowly over a couple of centimeters (typically 4cm for a 10Hz setup), introducing cracks in the building structure above, but normally not causing its total collapse when well engineered. Two hours of structural stability during fire must always be a fact, in order to have the building evacuated. However, insurance companies may demand some basic fire resistance for the isolators by means of fire-resistant flexible joints installed around the elastomer pads, so that a small fire event doesn’t result in major reparation costs. Other possibilities are the use of fire-resistant plating based on gypsum, attached to the suspended part of the building, but not in stiff connection with the base (e.g. making use of a fire-swelling strip, closing off well the vibration cut in case of excessive heat), to avoid transmission of vibrations. One could also consider the installation of the isolators in a fire-free compartment, some kind of extra level under the suspended part of the building, that remains accessible for regular inspection.
As to helical springs, one can over-dimension the steel spring wire so that the springs resist mechanically to a fire of 2 hours. But here as well, insurance companies may impose some basic

fire resistance to keep the consequences of a minor fire event limited, e.g. by using fire-resistant plating as explained above.

3.4.3. Water penetration risk

When cutting a building below groundlevel, there exists a risk for water penetration in the vibration isolation cut. Water is volumetrically nearly uncompressible, so a well-designed drainage system should avoid possible stagnation of water between elastomer pads installed under column feet for instance. Another possibility is to have the elastomer pads incorporated in a light closed-cell foam material that doesn't absorb any water, like EPDM. Such material can also be used as a mat, wrapped around the building perimeter, in order to avoid the penetration of water here, and still creating a flexible layer (eliminating bridging with the soil).
Steel springs and their housings should always be well protected against corrosion (rust), especially in case of humid environments. Thermal galvanization of the steel housings and epoxycoating of the springs is therefore a real must, and regular inspections are recommended.

3.4.4. Horizontal forces (wind / seism)

Dynamical forces like wind and seisms create important shear stresses in the isolators. By cutting the building at its base, one significantly weakens the structural stability of the building with respect to such forces, that create important horizontal displacements, but also vertical displacements (uplift). It is consequently necessary to perform a stability check with respect to wind for light tall structures, and with respect to earthquakes for seismic areas, in order to make sure that these forces can be fully transferred over the vibration cut towards the suspended part of the building. This can be realized by using failsafe mechanisms and isolated fixations. Note that during an earthquake or storm, the need for an efficiently functioning vibration isolation system is practically absent…
In case it is decided not to cut the stiff building cores (i.e. stairways, elevator shafts, etc.), it is important to introduce a resilient decoupling at all connections between the floors (which act as diaphragms) and these rigid cores, in order to avoid acoustical bridging. Another possibility consists in cutting the cores at a different level, e.g. 2 levels deeper than the overall vibration cut, to increase the lateral stability of the building. Or another option consists in applying a gradually increasing stiffness, as one moves further away from the trackline, towards a fixed connection; the further away from the track, the smaller is the required isolation efficiency…

4 POSSIBILITIES FOR EXISTING BUILDINGS

4.1 Precompression of elastomers through freezing

Until recently it was almost unthinkable to cut existing building structures for introducing noise and vibration isolators underneath. But with newly developed techniques, it has now become possible to have existing buildings installed on elastomer pads realizing a cut off frequency of about 10Hz, at economically defendable costs. It is however important that the building structure is reasonably uniform and mainly based on columns. The elastomer pads are then precompressed at a load corresponding to 100% ADL in the lab using deep-freezing at -80°C (below the glazing temperature) and installed on site between 2 galvasteel plates at the column / wall which is under treatment. The ambient temperature warms up the deep-frozen pads, which slowly become capable of taking up the loads, practically without any vertical movement if well engineered. This method must be applied column after column, using temporary studs, in order to secure the overall stability of the building, and can therefore take several weeks or even months, but without major disturbance for the people working or living there.

4.2 Flexible soil screens

In case there is no possibility to isolate the track infrastructure in an economical manner, and there's (several) existing buildings situated nearby and being disturbed by the vibrations generated by the rolling stock (through secondary noise), one can still consider the option of introducing a flexible soil screen (barrier) in between source and receiver (also "trench isolation"). As the shear wave component in the soil is of major importance and peaking at 45°, the depth of such a soil screen needs to be determined in function of the distance to the track(s). This results in a depth of several meters, even down to 15m in some cases. A flexible soil screen consists of a stiff concrete screen onto which a flexible layer is attached with a stiffness module and density significantly lower than the concrete, in order maximize the impedance jump. Such an impedance jump in the soil reflects the wave energy then backwards. When using a flexible material with a high internal damping, part of the still transmitted wave energy is absorbed, so the energy entering the building foundations can be strongly reduced (with 10 to 15dB).

5 REFERENCES

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