Izmir Transportation Symposium

Modern Technology of Anti Vibration and Noise Control applied on Tramways

By

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1 Introduction

Tramway becomes more important for urban centers in the future. The renaissance of the tramway started in the 80^{th} in a new, modern form. Between 1981 and 2004, 41 cities worldwide reinstated tramways that have previously been discontinued. In congested areas the close vicinity of tramways to buildings is an unavoidable conflict in respect of the transmission of noise and vibration to people or sensitive equipment. GERB have developed a variety of antivibration bearing systems which successfully reduce tram induced vibration. This paper illustrates different floating trackbed systems at grade.

2 Vibration Criteria

Vibration criteria are defined to limit the impact of the vibration on the environment. The criteria for acceptable ground-borne vibration are expressed in terms of vibration velocity level or, in respect to the German DIN 4150, in equivalent KB –Values. ISO 2631, "Continuous and shock-induced vibration in buildings (1989)" and the DIN 4150 are commonly used standards.

The ISO 2613 standard defines a base curve and, depending on the building purpose (hospital, residential buildings and offices), different multiplying factors V. The factors depend on the location and consider human perception. The strongest criterion is defined for hospitals and precise, laboratories while the highest vibration levels are accepted in workshops.

Place	Time	Continuous vibration	Transient vibration with several occurrences per day
Critical working area **Hospital operation theatres**	Day Night	1	1
Residential	Day	2 to 4	30 to 90
	Night	1,4	1,4 to 20

Office	Day Night	4	60 - 128
Workshop	Day Night	8	90 to 128

Table 1: Multiplying factors according ISO 2631

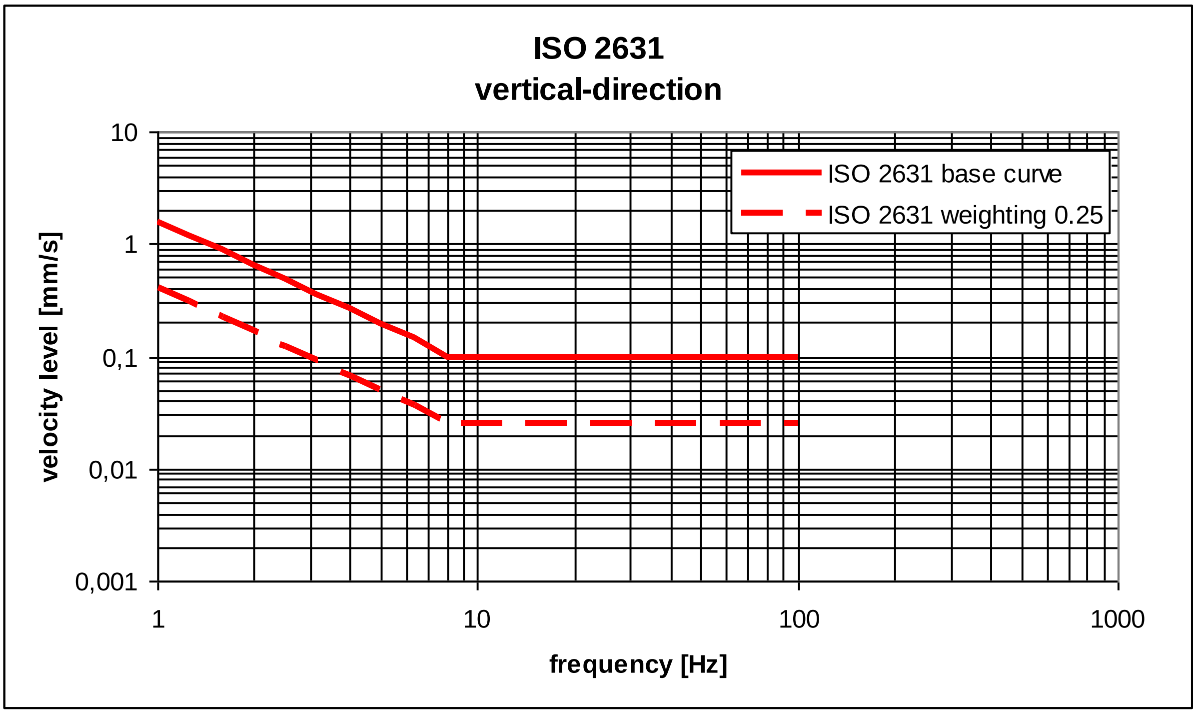

Figure 1: vibration criterion according ISO 2631

The German DIN 4150 considers only residential purposes in different land-use categories. Compared to the ISO 2631, the DIN 4150 uses so called KB values which consider the human response on vibration. Depending on the amplitude and duration of the vibration different limits are defined. The official guideline of the Ministry of Transportation (USA) defines three vibration categories.

No.	Category	Description
1	Highly sensitive	Buildings where vibration would interfere with operation like concert halls, vibration sensitive research,…
2	Residential	The category covers all residential land uses and any buildings where people sleep. No differentiation is made between different types of residential areas.
3	Institutional	This includes schools, churches, or other institutions, and quiet

		offices

Table 2: vibration categories

Category	Frequent Events	Occasional Events	Frequent Events	Occasional Events
1	65 dBv	65 dBv	-	-
2	72 dBv	75 dBv	35 dBA	38 dBA
3	75 dBv	78 dBv	40 dBA	43 dBA

Table 3: recommended vibration and ground-borne noise level for different categories

3 VIBRATION ATTENUATION MEASURES

Noise and vibrations radiating from rail tracks are mainly generated by the contact between wheels and rails. In the long run rail corrugation and deformation of wheels are almost unavoidable. A great deal of maintenance is required to keep the quality of the contacting surfaces within acceptable limits. The periodical grinding of rails in long track sections within sensitive areas is as expensive as the after-treatment of the wheels.

Finally, the application of vibration attenuation measures may be more practicable and cost saving. Quite a number of techniques have been developed which differ significantly in efficiency and costs. Rail and baseplate pads mainly provide elasticity to the track as especially required in the case of a slab track system rather than reduce noise and vibration radiation. In this respect, other systems like embedded rails or ballast mats can be expected to be more effective but at a higher cost.

4 FLOATING TRACKBED SYSTEMS

There is no doubt that the best performances in terms of vibration attenuation can be achieved by floating trackbed systems if they are well designed by experienced engineers. These mass-spring-systems (MSS) consist of floating slabs with the rails mounted on top. The slabs are usually constructed of massive concrete. Together with the dead load of rails, sleepers and fastenings (and the ballast, if any), they form dynamically active masses which are isolated from the sub-structure by elastic mounts which may be of rubber, elastomeric material or steel.

The performance of a MSS depends on a number of factors. Besides the vertical tuning frequency, the bending natural frequencies of the slabs are of significant importance. In addition, the system damping as well as the stiffness of the sub-structure have a clear influence. Finally, the success of a MSS can also depend on the dynamics of the tunnel itself. In certain cases there is little advantage to be obtained by using a medium-frequency (say above 15 Hz) floating-slab track construction in railway tunnels [1].

Since the tuning frequency depends on the static spring deflection, it is obvious that the spring stiffness is the most important issue. Fig. 2 shows the transmissibility factor V_F over the tuning factor η. The tuning factor is defined as the ratio of the excitation frequency f divided by the natural frequency f_z. It clearly shows that attenuation of vibration transmission takes place only if the factor is beyond the value of $\sqrt{2}$ .There is no reduction of dynamic forces possible when the natural frequency (= tuning frequency) of a MSS is close to or above the relevant excitation frequencies.

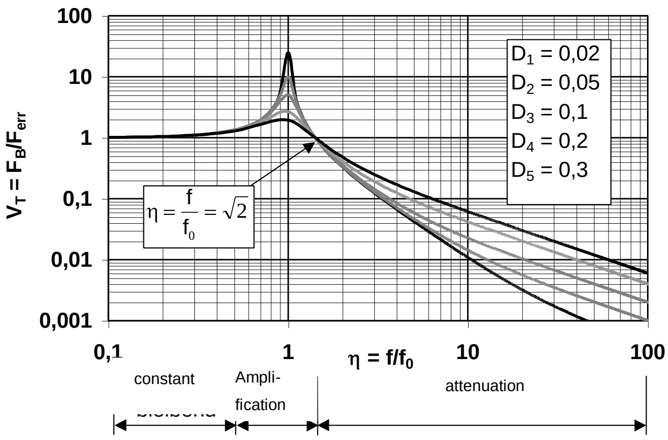

Figure 2: transmissibility curve depending on damping

Typical vibration frequencies induced by trains are found in a range of 10 - 80 Hz. The frequency spectra usually reveal a concentration of higher peaks in the 60 Hz area, e.g. due to natural frequencies in the bogie system. However, quite often there are high vibration levels between 10 and 30 Hz as well.

In the case of a standard trackbed, these frequencies might cause severe vibration problems in nearby buildings showing resonance frequencies just in that range. Even a MSS with a resonant frequency as low as 10 Hz would not provide sufficient mitigation. And things go from bad to worse, when a costly MSS, designed to a 10 Hz tuning frequency, actually shows 12 - 15 Hz which would then be close to resonance. The only solution for this scenario is to choose a so-called ' low-tuned ' mass-spring-system. Steel springs can be relied on to provide a tuning frequency below 7 Hz.

Since the tuning frequency of a floating trackbed is so important, it has to be explained how it is defined. As a first approach, the extension of the slab can be neglected and all spring stiffnesses of a direction can be united as one common spring. This results in a single-mass-system with 6 degrees of freedom. With respect to the direction of the dominant train excitations, here the vertical translation natural frequency is the most relevant one here referred to as the 'tuning frequency'. A linear spring elasticity provided, the tuning frequency of the non-damped system can easily be calculated by the following simplified equation:

$$f_z = \frac{5}{\sqrt{\delta[cm]}} [Hz] \qquad \text{with} \quad \delta = \frac{F}{k_z}$$

Although the actual correlations are much more complex, the tuning frequency can be used to evaluate the efficiency of a floating trackbed system at a first view.

Sometimes the non-suspended part of the rolling stock is added to the mass leading to a lower tuning frequency. This part is usually chosen at 1/5 – 1/3 of the axle loads contributing to the sprung system.

A more realistic results is achievable by modelling the slab according to the Finite- Element-Method (FEM). In this case the flexural modes of the slab are taken into consideration. This is of special importance when the 1-order bending natural frequency of a slab is in the same range as the tuning frequency resulting in coupled modes. The tuning frequency will be shifted, and a diminished tuning factor might result in a reduction of the isolation efficiency of the system.

5 GERB Floating Slab Track (FST) for tramways

GERB has developed a special FST for tramways at grade. The common construction is as following:

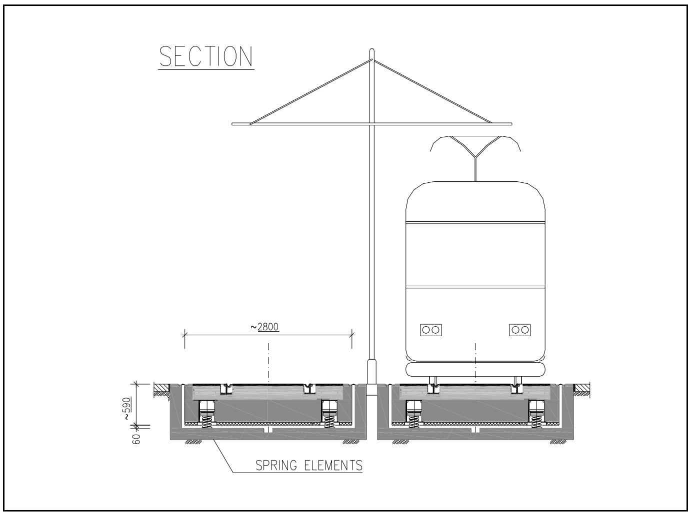

Figure 3: Principle cross section of a FST at grade

The slab supported on integrated GSI(V) elements is embedded in a shallow concrete pit. Sealing of the gaps between slab and pit walls and a suitable drainage prevent flooding of the pit.

The concrete slab, constructed on top of the bottom slab of the pit, is lifted stepwise by means of a hydraulic jack applied to the springs. Trams had already restarted operation when the final adjustments were done. The vertical spring deflection due to the tram passage is about 3 mm.

This principle construction was performed at many projects. For some international examples the basic data are presented.

5.1 Bielefeld; 1996 (Germany)

A tram passing in front of a Hotel in the city of Bielefeld/Germany caused non acceptable vibrations inside the old building. A new switch is expected to make the situation worse. It was decided to isolate the track from the ground by means of steel springs. The MSS was tuned to 5 - 6 Hz.

A 60 m long concrete slab of 600 mm thickness was designed to support the track including the switch. On top of the slab asphalt was laid since the slab is part of a street used by car traffic.

Figure: 4 Tram passing over a floating slab left: during construction and right: today

Finally vibration velocities were measured on top of the isolated slab as well as next to the slab and next to the adjacent conventional ballast bed. Attenuation values were recorded up to 25 dB between 12 and 100 Hz. The design tuning frequency of 5 - 6 Hz was confirmed. To the satisfaction of the owner, the vibration level inside of the hotel has proved to be below the threshold of human perception.

5.2 Frechen 2000 (Germany)

In Frechen the tram network was modified due to the operation of the new low floor tramway system. In the course of the modernisation, the installation of a turnout in front of a residential building became necessary. In the Bahnhofstraße the shortest distance from the frog to the outer brickwork of a residual building is only 4 m. Additionally, the building shows a resonant floor frequency at 9 Hz (wooden floor). Therefore the consultant advised to install a low tuned FST to avoid any increase of vibration level inside the building.

The design frequency is 6.5 Hz with a first bending mode at 10.6 Hz. Vibration measurements have shown high isolation of the vibration levels even withal of the installation of a turnout.

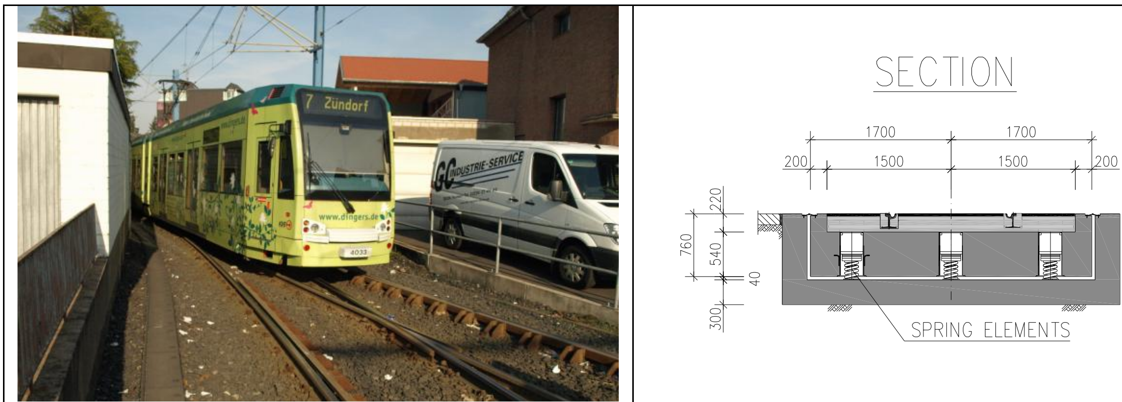

Figure 5 finished FST after 9 years of operation

5.3 Charlotte 2003 (USA)

The convention center is located in downtown Charlotte. The Light Rail Track (LRT) line runs through the Convention center in close proximity to conference and exhibition areas. Without any mitigation high levels of ground borne noise and vibration were expected. Therefore the GERB FST system was installed to isolate the vibration.

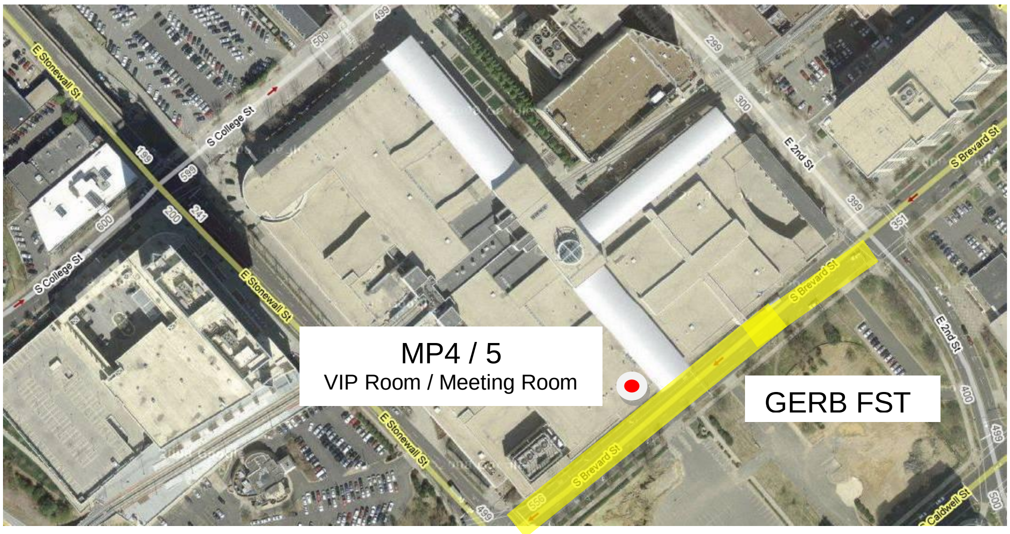

Figure 6: Top view of the Charlotte Convention Center

Figure 7: Tram passby through the convention center

The natural frequency f_0 of the slab can be obtained by an impact excitation of the FST and subsequently measuring the oscillation. The FFT shows two (2) peaks at 6.0 Hz and 7.25 Hz. This agrees well with the design frequency f = 5.2 Hz. As the trapped air in the gap which is worsened by the rubber profiles installed in the joint acts like an additional air spring. The effect is well known and leads here to an additional stiffness of about 30%.

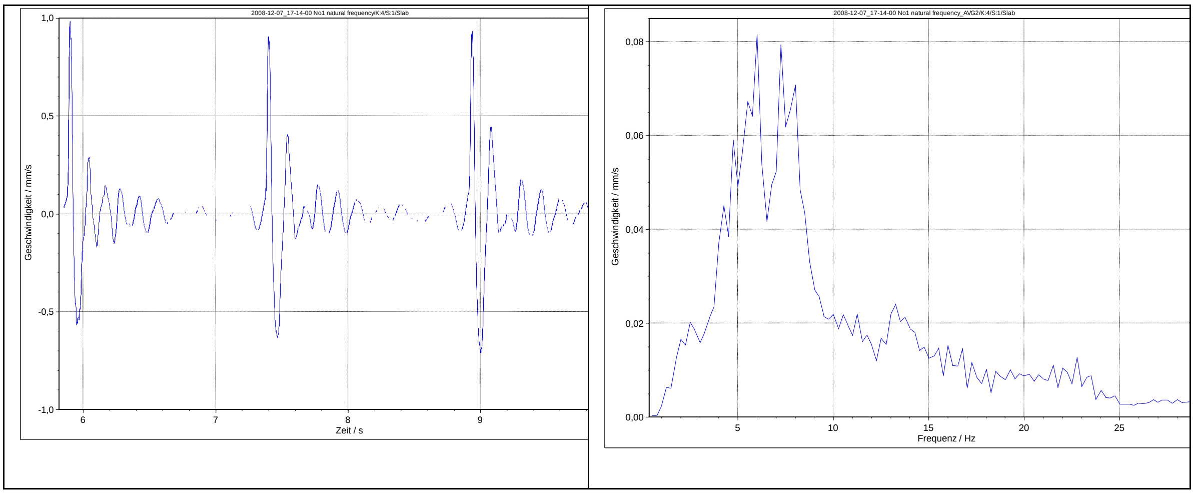

Figure 8 time history and FFT of the FST excitation

In addition to the vibration level at the track, vibration measurements are also taken in inside the convention center in close proximity to the track. Figure 9 shows the result of the measurement. As from the independent Wyle Labs expected, the vibration level in the meeting room is lower than the level in the VIP Room. The maximum of 0.02 mm/s occurs at 2.5 Hz. The vibration is not noticeable.

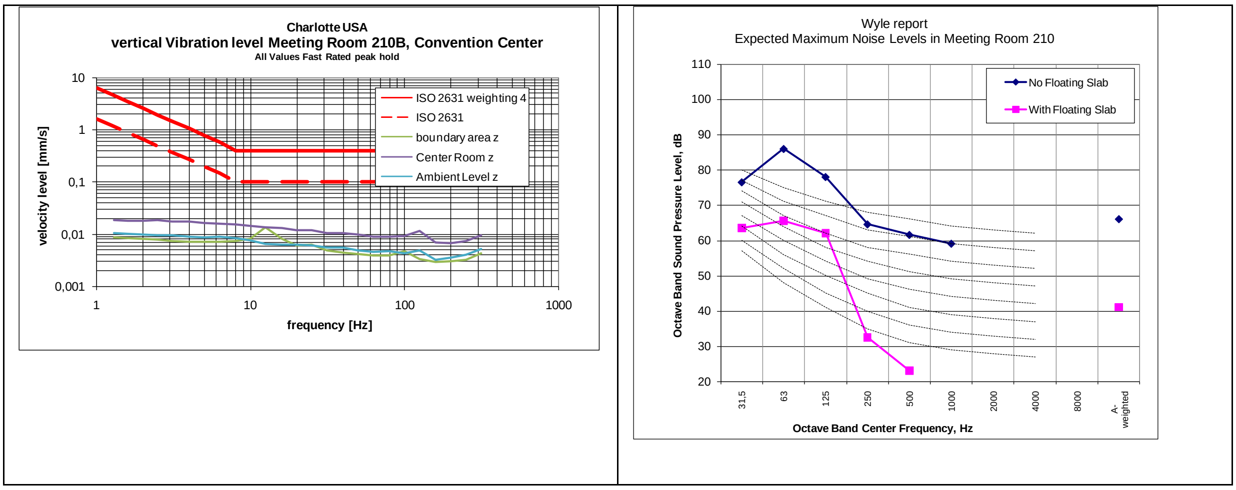

Figure 9: vibration and noise level inside the Convention Center

5.4 Basle 2006 (Switzerland)

The Steinberg in Basle is one of the most heavily used section of the city LRT network with LRV passing of one or two minutes. The close vicinity to the concert hall, reputed to be one of the ten finest acoustics in the world, leads there to rumblings and avoids any recording of concerts. Ten of eleven Basles tram lines run next to the Music Hall, approximately 60 times per hour during the evening. The T-crossing at the Theaterstraße and Steinenberg is a high source of sound and vibration emissions due to the arrangement of crossings, turnouts, and tight curves.

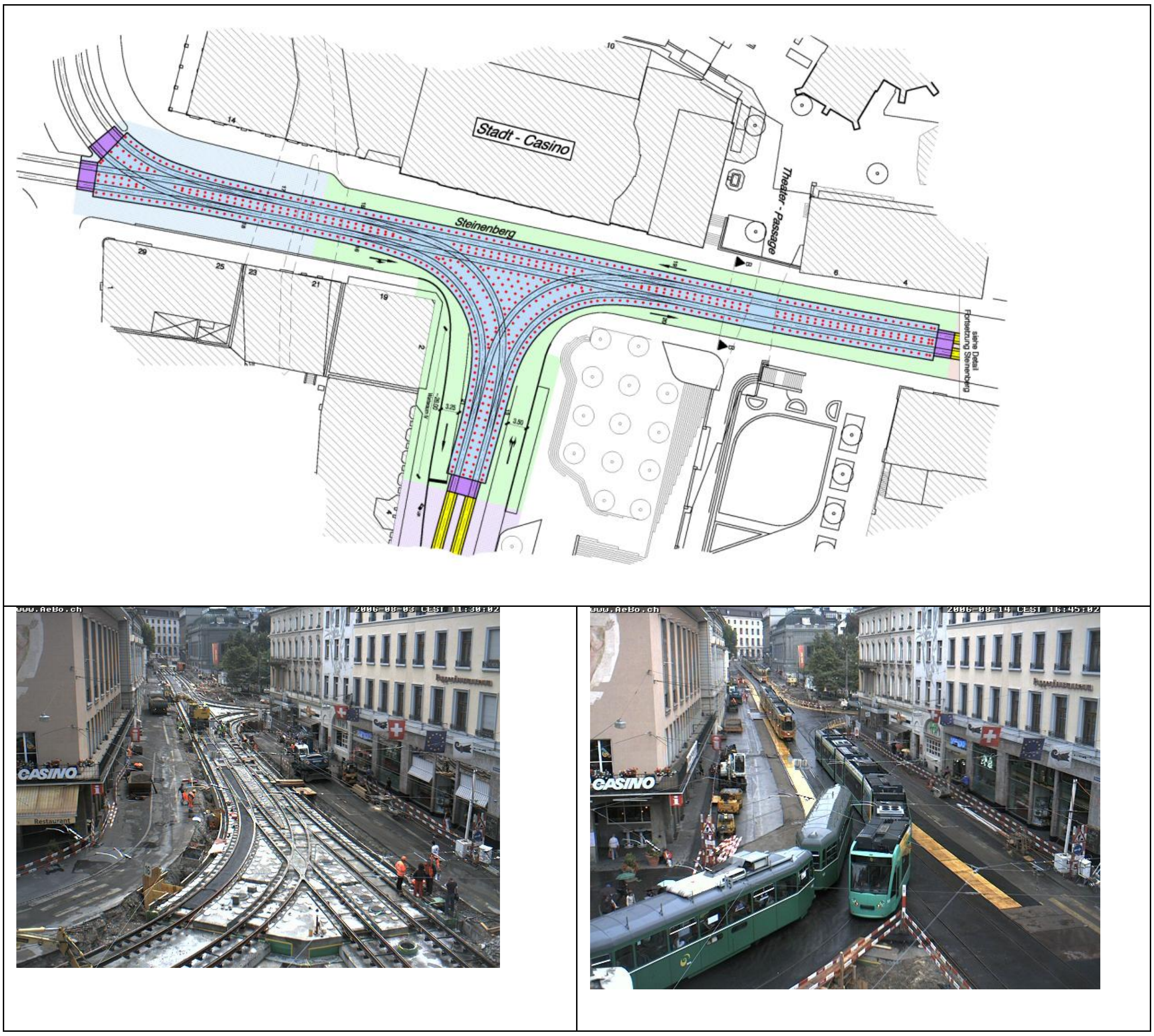

Figure 10: FST in Basle

The solution was installing a 5 Hz GERB FST with an extraordinary height of 1.05 m. This was necessary to limit the deflection by passing heavy trucks. A total of 750 steel springs were installed. Another special was the fact that the construction of the approximately 170 m long FST was completed within 6 weeks.

With this measure the noise in the concert hall has been reduced by 22 dB. Vibration measurements were conducted by an independent consultant before and after the installation of the measure. The results are shown a high performance between 16 Hz and 80 Hz with an insertion loss 25 dB up 30 dB.

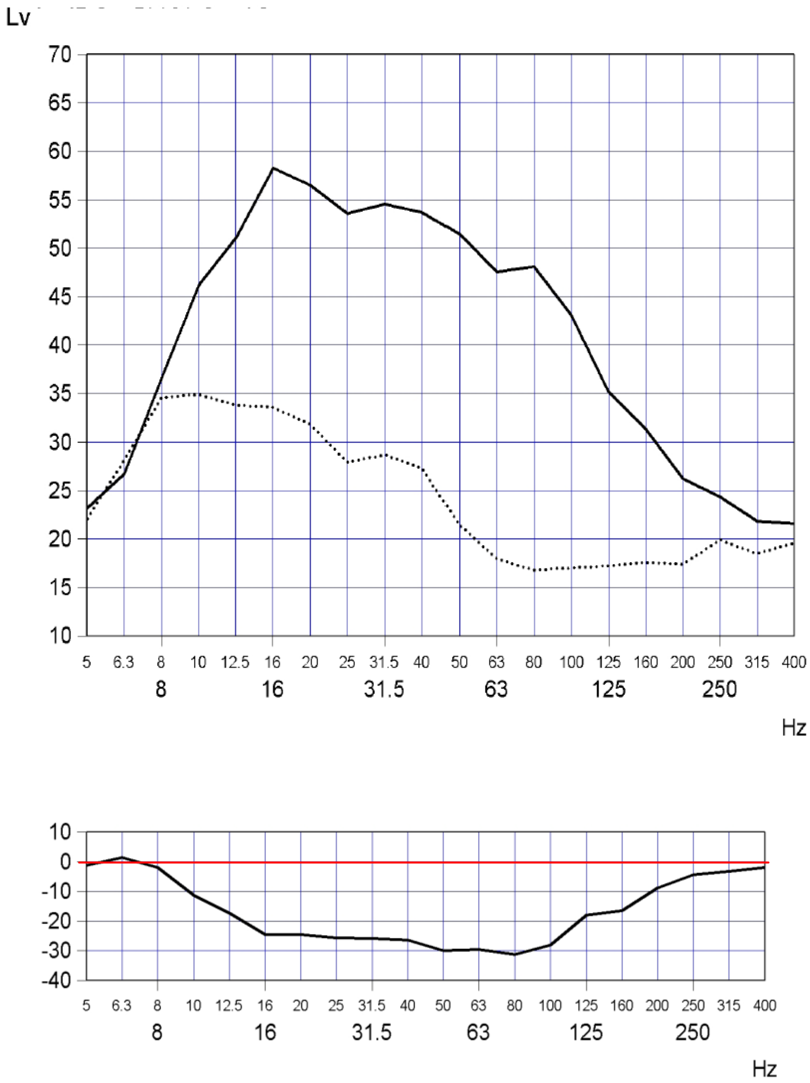

Figure 11 vibration level before and after the installation of the FST, respective the insertion loss (Source: IBU, Essen)

6 Summary

With well designed, low tuned floating trackbeds high vibration attenuation levels can be reliably achieved. Supported on steel springs, long slabs provide advantages in terms of construction, installation and performance. Several applications for FST at grade are shown allowing meeting the international vibration criteria.

Literature:

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