

Floating Slab Track above ground for Turnouts in Tram Lines

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Abstract

Trams can be seen in many cities all over the world. There is undoubtedly a remarkable revival of their use. Trams are an effective means of mass transit that can move large crowds directly to the downtown shopping and work areas. Inevitably, some tracks will have to be routed through narrow streets in close proximity to buildings. In these cases, abatement measures are required to avoid the transmission of noise and vibration which otherwise would annoy residents. When conventional measures such as rail or baseplate pads, embedded rails, or ballast mats are not efficient enough, then the installation of a floating slab system should be taken into consideration. Especially in the areas of crossings and turnouts, high-performance floating slabs are often the best choice. The present paper presents several applications of low-frequency floating slabs using steel springs thus achieving the highest possible reduction in noise and vibration levels. Highlighted are two projects commissioned in 2006: The installation of floating turnout slabs in the narrow shopping street of a medieval village in the vicinity of Heidelberg/Germany, and a 5 Hz floating slab system in Basle/Switzerland meeting the requirements of heavy tram congestion directly in front of a concert hall known as one of the finest in the world. The paper presents specifications, solutions, construction details, and measurement results.

1. Introduction

Crossings and turnouts are critical components of Railroad systems due to the negative impact on the surrounding environment. To a certain amount, structure borne noise and vibrations can be controlled in regular track segments by utilizing a resilient track bearing with a specific elasticity. However, such solutions are often not sufficient for crossings and turnouts. These critical parts of the track generate sound and vibration emissions far higher than regular track segments. In some cases, elastic rail bearings are not viable solutions. Furthermore, if buildings with “soft” slabs that are easily excited by low frequency rail activity are within close proximity of the track, vibration control systems with higher isolation efficiency should be used. In these cases, floating track slabs, if designed properly, will provide the highest possible degree of isolation. There are cases, where, due to cost reasons, within a track section only turnouts and crossings are isolated.

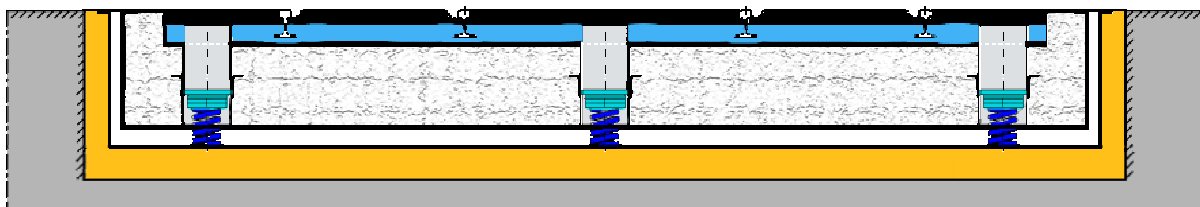


Fig. 1. Typical floating slab for a turnout in a tram line at ground level

2. The Spring-Mass-System

The spring-mass-system usually consists of a concrete slab, which is supported by an elastic vibration isolation layer. The rail system is mounted directly on the concrete slab or on a ballast bed. In order to hold the ballast bed, concrete slabs are shaped like a trough.

The elastic vibration isolation layer can be an elastomer material or consist of helical steel springs. The degree of vibration isolation greatly depends on the material selected in addition to the weight and geometry of the slab.

Effective vibration isolation can only be achieved when the system natural frequency of the trackbed is, by a factor of $> \sqrt{2}$, below the expected excitation spectra. Railroad systems typically generate a wide-ranging excitation spectrum of high energy excitations between 40 - 80 Hz. However, the concentration of excitation can even be as low as 10 Hz.

A spring-mass-system with a 5- 8 Hz vertical natural support frequency will provide effective isolation in the entire excitation spectra, even in the case of excitations in the 10 Hz range.

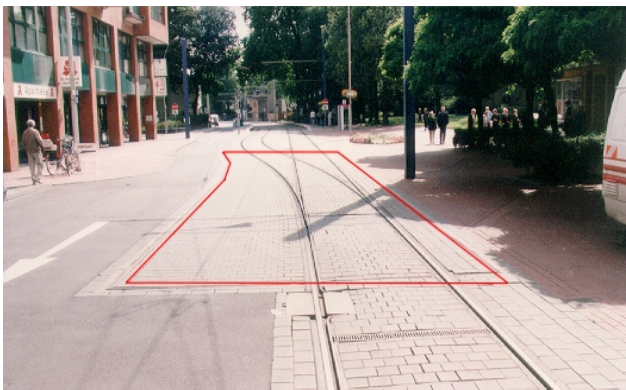


Fig. 2. Plan of a FST turnout slab in a tram line at ground level,

Fig. 3 View at top of the concrete slab

A low tuned spring-mass-system with a vertical system natural frequency below 12 Hz is often described as a “heavy” spring-mass-system. “Heavy” refers to the large mass that is necessary to achieve a high level of deflection needed in the elastic support layer. However, selection of proper materials with high elasticity can aid in the design of a low tuned frequency system with significantly less mass.

Train dynamics will strongly dictate the technical requirements and hence the above-mentioned reduction in slab mass. Requirements vary from train system to train system. When high-speed trains are compared to subways or trams, design criteria vary greatly. Therefore, spring-mass-systems have to be carefully designed to meet both isolation efficiency and also technical requirements due to train dynamics. Dimensions of elastically supported slabs are therefore specific to each project, considering local limitations and guidelines.

Furthermore, special requirements are necessary in the design of a spring-mass-system for trams when the tracks are at street level and in most cases part of the street. This requires that the tracks

support load from motor vehicles and even heavy trucks. The dynamic deflection of the system has to be carefully designed to provide for a smooth transition when heavy vehicle ride on the slab. Also, the gap between slab and street has to be carefully considered. Here the choice of a slab mass heavier than usually required, e.g. in a tunnel, will be advantageous. Because of the high amount of spring stiffness required, the dynamic vertical displacement of the system will be sufficiently limited to a few mm without sacrificing the low tuning.

3. Helical Steel Springs in the Spring-Mass-System

Helical steel springs have been used since the early 1990's to provide the elastic layer in the spring-mass-system. Helical steel springs yield a high level of isolation against structure borne noise and vibrations in the rail vicinity. It is used in the isolation of tracks in tunnels, at ground level, or in bridges and viaducts. Steel spring elements are even used as vibration isolation bearings for bridges.

Furthermore, helical steel springs have been used as bearings in the permanent way of subways, trams, cargo and passenger trains and high speed trains. For example, parts of the Frankfurt International Airport Skytrain viaduct are isolated with helical steel spring devices in spite of the fact that the train is equipped with rubber tires. The viaduct is isolated in parts that are close to VIP lounges and waiting areas where high levels of structure borne noise control and vibration reduction is desired.

Helical steel springs are contained in steel housings for track isolation applications. These housings are placed in lateral recesses of the slab or embedded while the slab is poured. The first option (KY-System) requires lateral access to the elements while the latter (GSI-System) provides access from above. The GSI-System has proven very effective for the isolation of crossings and turnouts. The benefits of the system are:

- The horizontal overall span of the spring-mass-system can almost be limited to the dimensions of the isolated slab.
- Spring elements can be placed between ties and rails so that the spring support system does not interfere with the operation of crossings and turnouts.
- The Spring housings are embedded in the slab when it is poured. The springs are later placed from above and activated.
- The concrete slab can be poured on top of the foundation slab. The concrete slab is later lifted by a special jacking device. The system allows levelling of the slab within a few millimetres. Complicated jacking mechanisms are not necessary in this case.

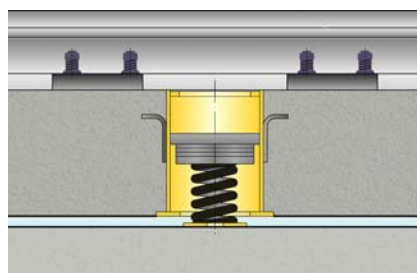


Fig. 4. GSI spring element
embedded in a track slab

4. Isolated Turnout Slab in Heidelberg

Two spring-mass-systems were installed in turnouts 92 and 93 of the new single track tram system in the German city of Heidelberg (Kirchheim suburb). The systems were installed in turnouts before and after the “Schwetzinger Straße-Odenwaldplatz” stop. The vibration isolation measure of the 25-meter long turnout slabs (Fig. 5) limits structure borne noise and vibration emissions to buildings in the nearby area (Fig. 7,8). The width of the slab varies from 2.8m to 5.2m.

According to the project specifications, the unloaded system was to be designed with a theoretical vertical natural support frequency of 8 Hz. The isolation layer was to be provided by helical steel springs in GSI housings.

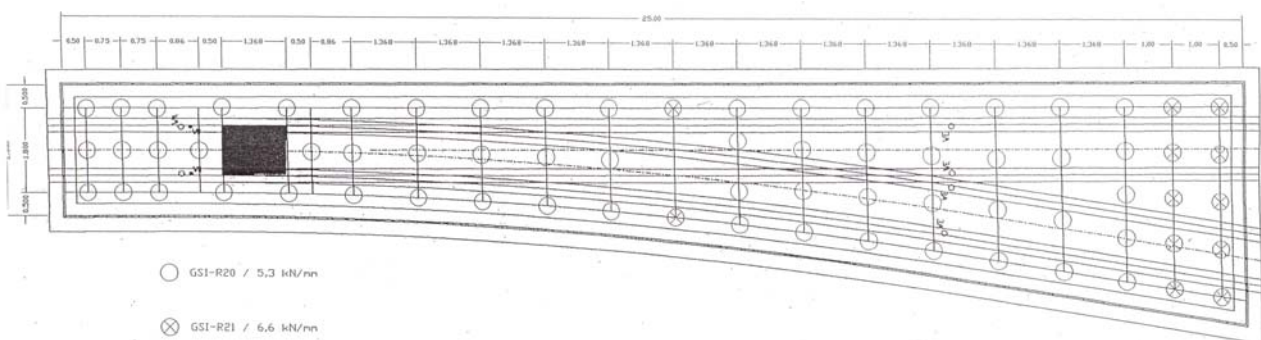


Fig. 5. Arrangement of spring elements in a Heidelberg turnout slab

Dynamic and kinematic rail calculations were provided in the planning stage by the consultant IBU Ingenieurbuero Uderstädt + Partner [2]. The goal was to determine the maximum rail stress and the fitness of purpose for the spring elements. The analysis included prove of deformations in areas of transition to the adjacent systems due to train transit (10 t load per axle), braking, lateral impact and temperature variations.

Both spring-mass-systems are identical, but are arranged in mirror-image to each other. Each turnout is supported by 59 spring-elements type GSI-R20 ($K_v=5.3\text{kN/mm}$) and 12 spring-elements type GSI-R21 ($K_v=6.6\text{kN/mm}$). The spring-element layout is shown in Fig. 5. In addition, all horizontal loads are carried by the steel springs. Lateral restraints are not necessary.

Installation was performed in October 2006 and included the housing placement, mounting of spring inserts and the slab hoisting. The gap beneath the slab was set at about 40mm. Hoisting and levelling of the slabs was performed by 3 riggers in 3 working days (Fig. 8). Hoisting of the slab was started only one week after placement of concrete.

The joint venture handed over the turnouts to the owner “Heidelberger Straßen- und Bergbahn AG” in December 2006, who has been operating the turnouts since. The required measurements to determine the tuning frequency of the system are intended in July 2007. The cost for the GSI elements and their installation including the slab hoisting was €35,000 per turnout.

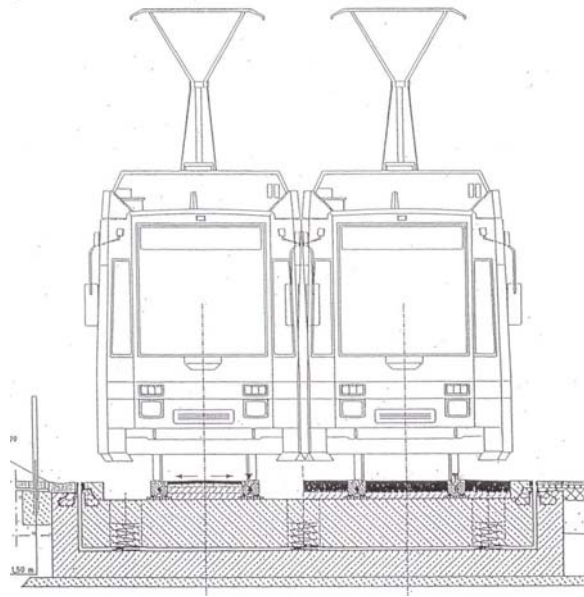


Fig. 6. FST cross section



Fig. 7. Slab construction, embedded spring housings



Fig. 8. Lifting of the concrete slab

5. The new Spring-Mass-System in Basle/Switzerland

The Basle Music Hall was edified in 1876 and is considered one of the finest ten Concert Halls in the world. However, the joy of a perfect concert experience was heavily infringed upon since many years ago by structure borne noise and vibrations generated by nearby tram transit. The dramatic conditions even made some famous artists and orchestras to refuse to perform.

Ten out of the eleven Basel tram lines run next to the Music Hall, approximately 60 times per hour during the evening. The T-crossing at Theaterstrasse and Steinenberg is a high source of sound and vibration emissions due to the arrangement of crossings, turnouts, and the tight curves. Even damage to the building structure has been attributed to the tram layout. The planned improvement and renovation works in the hall and the reconstruction of the adjacent City Casino provided an op-

portunity to deal with the unfortunate situation using a spring-mass-system. A generous donation of a local trust also contributed to the project.



Fig. 9 Tram track system in front of the concert hall before replacement

The main goal was to reduce the noise level inside the empty concert hall of about 46 dB(A) by at least 20 dB(A). A good deal of the registered noise in the empty Music Hall was in the 40-60 Hz range [1]. The low frequency range of the spectra is especially critical, since the distinct resonance frequencies of the Hall is about 38-40 Hz. Therefore a system with a vertical natural support frequency of 5 Hz was selected for the application. This low tuning frequency could only be reached by “soft” helical steel springs supporting a stiff and massive concrete slab. The system, if planned and executed properly, guaranties the maximum technical vibration and structure borne noise isolation in the entire relevant spectra of 10-120 Hz and beyond.

Additionally, a disturbing noise level in the frequency range from 200 - 2000 Hz could not be ruled out. Therefore a “light” spring-mass-system was “planted” in the main system with a designed vertical natural support frequency of 17 Hz. The light spring-mass-system system consists mainly of a 30 cm thick concrete slab with lateral and base PUR-foam mat.

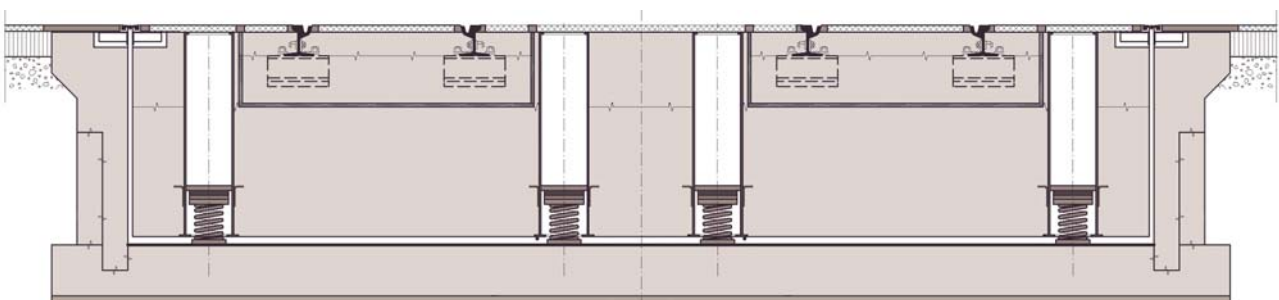


Fig. 10 FST cross section

Consequently, the total height of the spring-supported concrete slab is 1.05 m resulting in a high overall mass of about 3,000 t. In spite of the low tuned system with a 10 mm static spring deflec-

tion, the total stiffness of the resilient interface is quite high. Therefore there is only a small, almost imperceptible additional deflection of a few millimetres when tram and vehicle traffic runs over the slab. This small dynamic deflection is also a design advantage because it simplifies sealing of gaps.

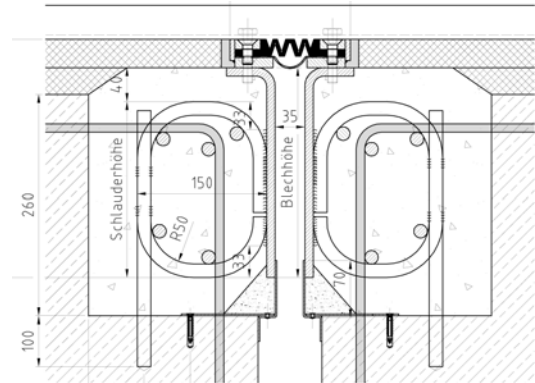


Fig. 11 Installation of the elastic joint sealing during tram operation Fig. 12 Detail [3]

A further challenge in the project was the design of smooth transitions between the spring-supported slab and the adjacent surfaces. In order to avoid an abrupt change in the stiffness, stiffer springs were placed in the transition areas. These special springs provide double the stiffness of “normal springs”. However, the high vertical stiffness allows for very limited dynamic horizontal deflections. Therefore, to account for thermal expansion displacements, here the spring system has been furnished with sliding contact bearings.

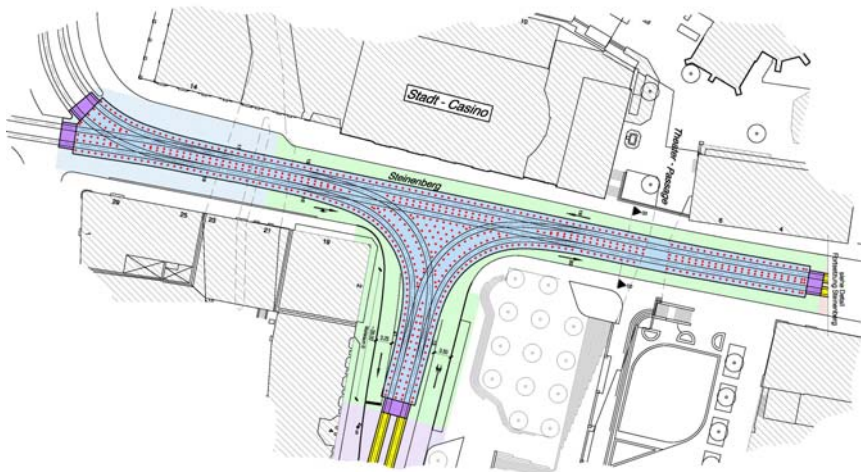


Fig. 13 Plan of the Basel FST

The floating concrete slab consists of 3 main elements and 3 end elements at the transition zones. A total of 762 springs were used for the application. The springs were arranged outside the rail range and placed from above into the spring housings once the concrete was cured. Then, the concrete slab, which was poured on site over a carpet-like surface, was lifted 50mm from the pit slab and levelled using a special jacking mechanism. This relatively simple tool was especially

manufactured with regard to the exceptional high housings. The hoisting process was performed in several stages to protect the concrete slab.

A special highlight of the project was the fact that construction of the approximately 170 m long spring-mass-system was completed within the 6 weeks school summer break. This was a requisite of the contractor because the tram circulation could only be completely halted during this time of the year.

The entire scope of work completed in the 6 available weeks included:

- Demolition of the old rail system
- Removal of old road surface/material
- Excavation work
- Construction of base slab
- Installation of pre-cast pit walls
- Construction of adjustment-foot directly below spring elements to compensate for street slope of up to 5%
- Placement of bond-breaking layer
- Installation of spring casings
- Installation of slab reinforcement and placement of concrete
- Construction of the light spring-mass-system
- Installation and commissioning of rail system.

The additional cost due to the “heavy” spring-mass-system totalled 3 Mio €.



Fig. 14 Lifting and adjustment of the track slab



Fig. 15 Spring units prepared for installation

Finally, it can be stated that the extensive but worthwhile procedure resulted in a noise and vibration level reduction of 22 dB(A) inside the concert hall. This world famous building has now, and after decades of exterior encroachments, been made available at its full value to the demanding cultural scene in Basle.

6. Conclusion

Within cities, tram lines are often located in the close vicinity to sensitive buildings. Here, floating slab track technology has proved to be the most effective and reliable solution to abate noise and vibration, especially, but not only, when radiated from turnouts and crossings. Helical steel springs used as the supporting element in a floating slab provide highest attenuation levels due to their low stiffness. The advantages are shown in the light of 2 projects having recently successfully been commissioned.

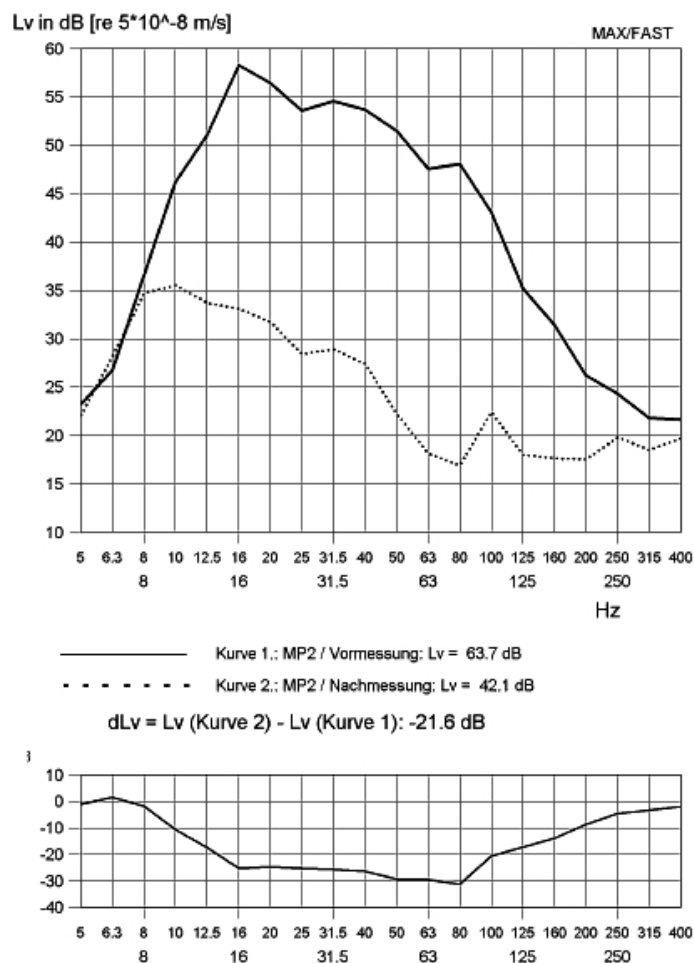


Fig. 16 Transmission curves (above: before and after; below: insertion loss) measured in front of the Basle Concert Hall [2]

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