A SLAB TRACK SOLUTION FOR THE REQUIREMENTS OF TOMORROW

M. Fink, Dipl. Ing, Sonneville AG, Switzerland
P. Laborenz, Dipl. Ing., Sonneville AG, Switzerland

SUMMARY

Together with Japan, Switzerland was one of the first countries 50 years ago to begin developing a slab track system, with the particular aim of providing long Alpine tunnels with a maintenance-free and durable track system that offers a high level of availability of the track infrastructure. The system chosen was a bi-block-sleeper encased with a rubber boot at the bottom and a resilient pad to create the necessary elasticity.

In this respect, the system has been continuously further developed and improved with the first milestone being the development of the single-block system LVT. This huge step enabled its use in the Channel Tunnel between England and France and further developments have brought the system to the next level. The proven track record as well as easy maintenance and noise and vibration advantages offered by this slab track system cover tomorrow’s general project requirements.

1 INTRODUCTION

50 years ago, development of a slab track system began at Swiss Federal Railways (SBB). It was aimed at offering a durable and low-maintenance type of track system for the long rail tunnels in the Swiss Alps. Together with Japan and the J-Slab system developed there in the 1960s, Switzerland can look back on many years of experience in slab track technology, which, in consideration of the increasing volume of traffic and maximum availability of the infrastructure, is gaining more and more in significance.

Based on the embedded bi-bloc-sleeper from the 1960s, the single-bloc LVT system was developed and was installed for the first time in the Channel Tunnel between England and France in 1990. The presentation shows the steps of the LVT development from the initial LVT Standard design through various projects with improvements to the standard system, the development of LVT High Attenuation and LVT for switches and crossings to the current installation in the Gotthard Base Tunnel (GBT), the longest railway tunnel in the world which is going into service in December 2016.

2 THE HISTORY OF SLAB TRACK IN SWITZERLAND

Given the significance of north-south transit rail traffic, in November 1963 an expert committee was given the task of examining different projects and requirements for Switzerland. Very early on it was clear that only non-ballasted track should be considered for a long Alpine tunnel. A system sketch for slab track was created in the Construction Department at Swiss Federal Railway (SBB) head office in May 1964 based on considerations from Japan (track for high-speed) and track suitable for a Gotthard Base Tunnel.

In parallel with SNCF (French Railways) and its Development Engineer responsible Roger Sonneville, a system featuring bi-block sleepers was chosen, the underside of which has been encased in a boot, in which a flexible pad ensures elasticity of the track and isolates the sleeper from the cast-in-place concrete into which it has been embedded.

In this respect, the following aspects were kept in mind:

- Choice of track components that were already well known to the track manager in everyday maintenance work,
- Ensuring of the required vertical track deflection and elasticity,
- Guaranteeing the interchangeability of all components and
- Simple track construction with a facility for checking and correcting the position before embedding in concrete.

As no dynamic modelling or laboratory testing of slab track forms were available at the time, all observations were carried out on a ‘trial and error’ basis either by using test tracks with special trains or installing test sections of slab track within existing operational lines.

An opportunity for a first short trail track came up with the construction of Bözberg Tunnel in the SBB network in 1966 [1]. The entire project was a huge success and showed that everything worked out as expected even in the long run. So in preparation of the planning of a Gotthard Base Tunnel, in 1974 a large-scale trial with the "Bötzberg Tunnel system" was carried out in the new twin-track, 4.8 km-long SBB Heitersberg Tunnel [2],[3].

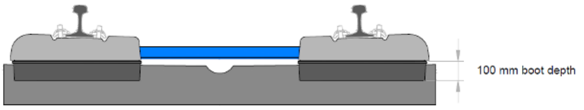

Figure 1. Section System "Bötzberg Tunnel"

The exchangeability of the rubber booted system was proven in 2014 when the first track of the Heitersberg Tunnel had to be restored. The filling concrete was still in good shape, so only the sleepers had to be exchanged. Working in short night breaks in with an average of 100 metre, the old bi-block sleepers, including the elastic components, were replaced by new B12 sleepers specially developed for the project. After the sleepers had been changed on the complete track length, it could be put back into operation at a full line speed of 140 km/h. No subsequent track geometry corrections or concreting work had to be carried out [4].

3 THE DEVELOPMENT OF LVT

3.1 LVT Standard

Based on the good experience in the Heitersberg and Bötzberg Tunnel, the system got installed worldwide in several projects. In Switzerland the system went through a modification to make the system safer for people walking the track for maintenance or in case of an emergency. In the Zurich Airport train station the tie bars connecting the two blocks were removed after the track was constructed. This solution added an unobstructed passway and easier cleaning to the track but also an increased gauge widening, which was still within the tolerance range [5].

For the Channel Tunnel project, the tolerances for gauge widening were very strict. Due to the good performance of the modified bi-bloc-sleeper, Mr. Roger Sonneville came up with the idea to eliminate the connection bar entirely and therefore create a 50% deeper embedment of the supports compared to the bi-bloc version.

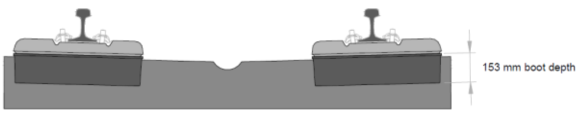

Figure 2. Section LVT Standard

In 1989 this new slab track system was prequalified to be tested at the Technical University in Munich, besides two other systems Stedef from France and PACT from the UK. All three systems were tested for compliance with the specifications for the honour of being the system chosen for this high-profile project. However, testing of the LVT system proved it to be the most compliant with the Eurotunnel specifications, based primarily on the results of the static and dynamic tests carried out on assembled rail support blocks. A major advantage of LVT is use of 'double resilience' in its rail support, i.e. two distinctive resilient components: the microcellular pad with a low stiffness located below the concrete block and a higher stiffness rail pad between the rail and the block.

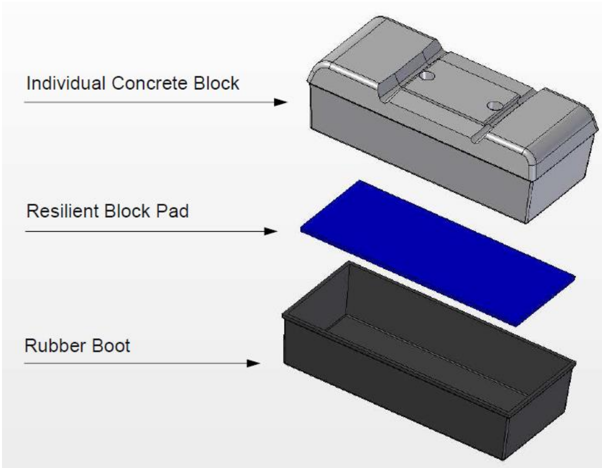

Figure 3. LVT Components

Besides the resiliency the LVT pad also generates a good load distribution for the entire track. Therefore the loads deriving from the train and transferred into the concrete are lower than a standard filling concrete (C30/37). Therefore reinforcement in the filling concrete is not necessary for the train loads.

The design of the slab track in the Swiss Zimmerberg Tunnel, which is part of the New Railway Link through the Alps (NEAT) and designed for a train speed of 200 km/h, is characterised by the fact that the LVT single support points are not only embedded in unreinforced infill concrete, but the lower concrete layer has also been designed without any structural reinforcement [6].

The LVT trackform was subsequently installed in the Channel Tunnel. In the meantime LVT has proven its choice by keeping the gauge widening within the tolerances and also ensuring an exceptional maintenance performance. In two incidents, both not related to track deficiency, supports were damaged and had to be exchanged. In short night breaks these supports were exchanged and train traffic could resume at its usual schedule. Other monolithic systems would create a much higher impact on the schedule as the restoration would require a removal of the entire slab track section.

3.2 LVT High Attenuation

With the successful completion of this project, LVT got a worldwide recognition and was installed in several occasions throughout the world. With the worldwide urbanisation, a reliable public transport became more and more important. In order to avoid traffic congestions on the surface, local authorities planned new lines underground. This created the problem of ground-borne-noise. Although LVT already has a certain level of noise and vibration mitigation, some areas called for a higher level. Up to the 1990s the solution for this problem was solely the use of mass-spring-systems. Although the performances of these systems in noise and vibration mitigation were excellent, the maintenance is difficult. In case the spring had to be replaced due to wear or malfunction, the entire slab had to be lifted, which is very complicated and also expensive. As an alternative for light mass-spring-systems, Sonneville developed the LVT High Attenuation system (LVT HA). The track can be maintained in the same way as LVT Standard without the use of heavy machines but ensures a higher level of protection against ground-borne-noise than other slab track systems.

After the installation of LVT HA in Los Angeles (Gold Line) and London (East London Line), the system was installed in the Citytunnel of the Swedish city of Malmö. The tunnel underpasses some sensitive areas and the initial solution was a mass-spring-system. With scientific calculations and support from the supplier of the resilient pads, Sonneville could prove that the use of LVT HA would keep the noise and vibration within the specified limits of v < 0.4 mm/s and 30 dBA. The authority accepted the change in design and LVT HA was installed 6 km long double track tunnel. After the completion of the project extensive measurements in several locations in basements above the tunnel were executed by an external acoustics bureau. Below table shows the results of the measurements.

Results form Measurement

Real Estate / measurement location	Structure-borne sound, L_{max} Slow	Vibration V_{RMS}	Comments
UMAS Entrance 25 Reuma ward 11, hospital room hall 6.	<25 dBA*	<0,1 mm/s	Measured at ward on bottom floor, no audible sound from the trains according to measurement personnel.
Kv Munken 7, Munkgatan 5	<27 dBA*	<0,1 mm/s	Measured in basement, some train passages were just audible according to measurement personnel.
Kv Guvernören 4, Banérsgatan 8	<25 dBA*	<0,1 mm/s	Measured in basement, some train passages were just audible according to measurement personnel.
Kv Kuratorn 3, Sommar-stadens studenthem, Cronqvist gata 10	28 dBA* (X61) 27 dBA* (X31)	<0,1 mm/s <0,1 mm/s	Measured in basement, some train passages were just audible according to measurement personnel.

Figure 4. Measurement results LVT HA [7]

As described in the table, some passing trains were only noticeable by the instruments and the personnel did not hear or feel anything.

Additionally in 2014 the insertion loss (IL) of the LVT HA system relative to a normal ballasted track in Citytunnel in Malmö was measured. The results show that the measured IL of the LVT HA system compared to the ballast track is about 31 dB at 63 Hz in the cut-and-cover tunnel and about 26 dB at 63 Hz in the drilled tunnel. The calculated IL is about 21 dB at 63 Hz. Below diagram shows that the measured IL is higher than the calculated IL at almost all 1/3 octave bands of interest (31.5-200 Hz).

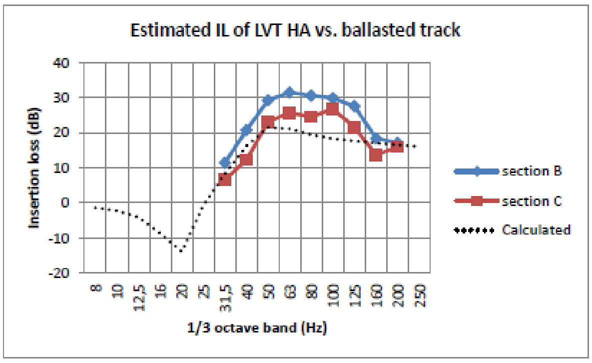

Figure 5. Insertion lost measured/calculated

3.3 LVT S&C

In order to have a constant track modulus throughout the entire project, Sonneville developed a solution for switches and crossings (LVT S&C). There are 5 different types of LVT supports, which differ only in length.

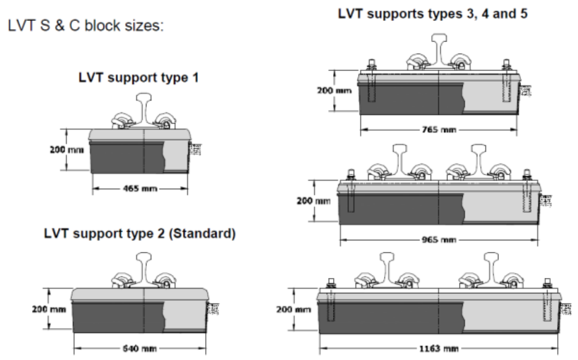

Figure 6. LVT S&C Supports

With the LVT S&C supports a highly standardized solution can be installed for every type of turnout that also offers an effective surface drainage. Below figure shows an example of turnout layout with LVT supports

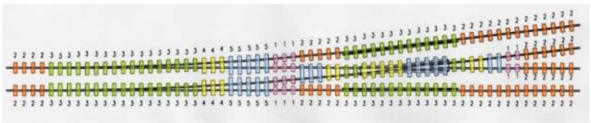

Figure 7. Typical layout of LVT S&C

3.4 LVT Traffic

With LVT traffic, vehicles with pneumatic tyres can also run on ballastless track. The general characteristics of the LVT system, like noise and vibration mitigation and easy maintenance, are also ensured with LVT traffic.

Modern rescue concepts are frequently based on vehicles running on pneumatic tyres going into tunnels. LVT traffic makes this possible: the combined track is realized by an additional cast-in-place concrete layer and newly developed LVT supports. These have high shoulders and can be separated from the cast-in-place concrete layer with special developed formwork covers. This means that LVT traffic displays the same exceptional behaviour in terms of track deflection and vibration mitigation as all previous LVT solutions.

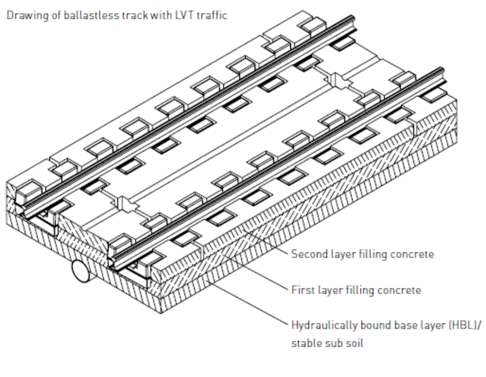

Figure 8. LVT traffic

4 LVT INSTALLATION IN THE GOTTHARD BASE TUNNEL

Given the anticipated extraordinary stresses on the track components in the GBT, they had to undergo extensive testing before they could be incorporated. The main aspects in this respect were durability and a long service life.

The high temperatures of around 40°C and high air humidity of approximately 70% in the tunnel pose extraordinary climatic demands, added to which are an anticipated track loading of 0.5 million tonnes per day, with a maximum axle load of 25 tonnes.

An essential part of the test programme, which was carried out at the Technical University Munich, were load cycle tests with in excess of 10 million load cycles, during which the ambient temperature to be expected in the tunnel was simulated.

Figure 9. Test set-up laboratory

These tests were broken down as follows:

- Determination of the static and dynamic (1 - 15 Hz) system modulus of rigidity before endurance testing "new" to the test specimens with an installation inclination of 0° and 22°
- Dynamic fatigue test with 10 million cycles, including with a load application angle of 22° at a temperature of 40°C, in order to simulate the worst-case temperature conditions that are predominant in the Gotthard Tunnel
- Determination of the system rigidity moduli on conclusion of the dynamic fatigue test and comparison of the values determined.

The test specimens exhibited support point spring rates between 28.4 kN/mm (load application vertical, static) and 43.7 – 50.0 kN/mm (load application under - 22°, dynamic). As regards the dynamic demands, both test specimens demonstrated a stiffening of approximately 30%, whereby from a loading frequency greater than 5 Hz, stiffening did not increase much more. Therefore the requirements of the ATG tender with regard to static rigidity of > 25.0 kN/mm with a horizontal installation, as well as a dynamic rigidity of < 55.0 kN/mm with an inclined installation were satisfied.

During the dynamic fatigue test, both test specimens were incorporated into the test machine simultaneously. Once the required temperature of 40°C had been reached, 10 million load changes were applied which have a vertical load component impact of 60 kN per support. One criterion of the endurance test according to the tender specifications is that the amplitude or the change in displacement amplitude is < 20 % from cycle 10^2 to 10^7. The other criterion is that no points that are worn through arise and the boot must not show wear of any more than 50% of the wall thickness at any point compared with its new condition. Both criteria were most certainly fulfilled by the test specimens being examined. Equally, a visual examination of the track system components after 10 million load changes revealed only slight signs of wear which it could be concluded were due to initial adjustment effects or possible restraints.

Working on behalf of the consortium, ARGE Fahrbahn Transtec Gotthard (AFTTG), Stans (Switzerland), following on from multiple trial runs in February and March 2014, dynamic deflection measurements were carried out in the Gotthard Base Tunnel during two test periods:

- 20 - 21 February 2014 with deflection measurements under an RE 420 at running speeds of 10, 80 and 120 km/h,
- 11 - 13 March 2014 dynamic deflection measurements under 2 x RE 460 + 3 brake vans + 1 driving trailer simultaneously with measurements for traction current supply at speeds of 160, 180, 200 and 220 km/h.

The runs took place in the western tunnel close to transverse tunnel 150, which lies about half-way along the approximately 13 km long Faido – Bodio test track. During these tests, the same instrumentation was arranged on the inductive displacement transducers at three cross-sections (left and right rails) as in laboratory tests (see Fig.9). Measurements were taken automatically during the two sets of trials and also monitored and saved on a computer at IP Biasca via a network link.

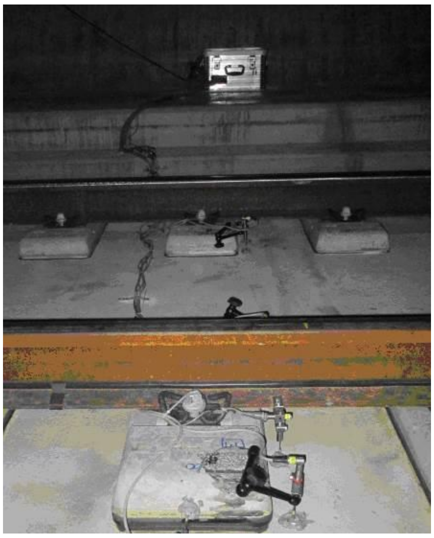

Figure 10. Test set-up track

Fig.11 shows the measured rail deflections when running over the measurement arrangement in the 2nd test campaign at a speed of 220 km/h at measurement cross-section 2. A 100 Hz low pass filter was used to analyse the signals. Fig.4 shows the average value of the maximum rail deflection under the locomotive axles for the trial runs at the respective speed levels.

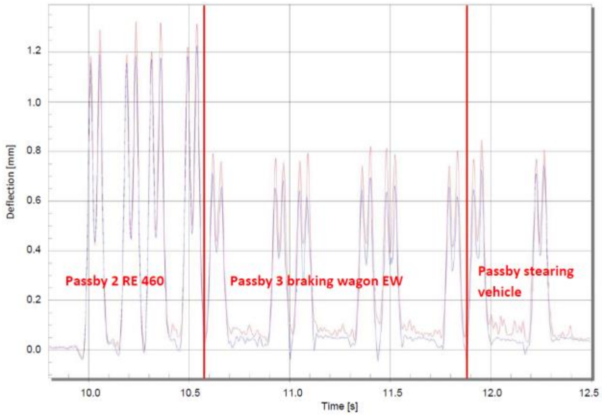

Figure 11. Deflection measurements

With regard to the dynamic deflection measurements, in summary it can be established that the rail deflection at the measured support points remained virtually the same at approximately 1.3 mm with both quasi-static and dynamic loading. The deeper deflections measured at running speeds of 80 km/h and 120 km/h can be attributed to the dynamic influences of the loading vehicle which have a greater effect on the deflection curve than the stiffening of the elastic material. A stiffening of 1.3 which was determined in laboratory trials in 2010 was not significantly exceeded during the measurements.

5 FUTURE DEVOLOPMENTS

As far as the further development of slab track is concerned, it is planned by various authorities to not only use the slab track system in tunnels, but in general wherever a rigid track subgrade exists. Therefore in Switzerland two bridges 394 m and 1,156 m long, which are part of the Zurich Cross-City Link, will be the first long bridges to be equipped with LVT in Switzerland. In other countries such as Brazil, England or USA, bridges have already been equipped with LVT and have proven their economic and technical advantages.

At the same time, development, especially for rail projects in built-up areas, is moving forward with the aim of finding a slab track system which offers improved protection against vibrations. And in the end it is not only against a background of improving acceptance of rail projects in inner-city areas.

Another development is going in the direction of replacing existing ballasted track in tunnels and on bridges with slab track, and ideally when still in operation so as to cause minimal interruption to the infrastructure. In particular in Switzerland with a large number of tunnels and a high density of traffic only offering a small window for maintenance work, this is an important aspect which should be kept under scrutiny in the coming years.

6 CONCLUSION

In order to make the use of slab track even more attractive to railway operators, further development is targeting faster and more efficient installation. Certainly, whilst the lifecycle costs of LVT slab track are currently about 8% lower than those of standard ballasted track, the investment costs are, however, still higher than in projects using ballast.

As the past has shown us, the further development of the slab track system and work to install it requires close cooperation between industry and rail operators, so as to achieve the best possible result and to obtain the overall Sonneville credo: **"*Make everything as simple as possible, but not simpler*"** (Albert Einstein).

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