Low-maintenance ballastless track structures

Increasing traffic density is steadily making it more difficult to carry out track maintenance and renewal. On Netherlands Railways (NS), night-time possessions often last no longer than 5 hours. In South Korea, the maximum effective night-time possession on the future 435 km Seoul-Pusan high-speed line is estimated to be no more than 1.5 hour. This article describes ballastless track structures offering low-maintenance solutions.

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Traditionally, railway track consists of rails laid on timber or concrete sleepers, supported by a ballast bed (Fig. 1). The main advantages of this type of track are [1]:

- relatively low construction costs;
- high elasticity;
- high maintainability at relatively low cost;
- high noise absorption.

Ballasted track, however, also has a number of disadvantages. For instance:

- over time, the track tends to 'float', in both longitudinal and lateral directions, as a result of non-linear, irreversible behaviour of the materials;
- limited non-compensated lateral acceleration in curves occurs, which is due to the limited lateral resistance offered by the ballast;
- at high speeds ballast can be churned up, causing serious damage to rails and wheels;
- over time, the ballast bed becomes less permeable due to contamination, grinding-down of the ballast and transfer of fine particles from the subgrade;
- ballast is relatively heavy, which leads to an increase in the construction costs of bridges and viaducts if these are to carry a continuous ballasted track;
- ballasted track is relatively high, which has direct consequences for tunnel diameters and track access points.

The rate at which the track deteriorates is closely related to the quality of its original construction, particularly with respect to the track geometry, the homogeneity and bearing strength of the subgrade.

On bridges featuring a continuous ballast bed, extra elasticity must be created by:

- installing a ballast mat between the ballast bed and the bridge;
- increasing the elasticity of the rail fastenings.

Reinforcing layers

Softening of the subgrade can cause major problems, especially in combination with vibration. Therefore, in Japan and Italy high-speed track is installed on a waterproof asphalt layer with a thickness of between 5 cm and 8 cm.

In order to distribute – and hence reduce – subgrade stresses, the thickness of this bituminous concrete layer can be increased to 15 cm or 20 cm (Fig. 2). The high maintainability of the track geometry inherent to conventional ballasted track is thus retained.

Asphalt layers could offer major advantages to the construction of new track designed for relatively high axleloads and high gross annual tonnage. In addition, the use of reinforcing layers on conventional track designed for passenger services could lead to a significant reduction in the frequency with which the track geometry has to be corrected.

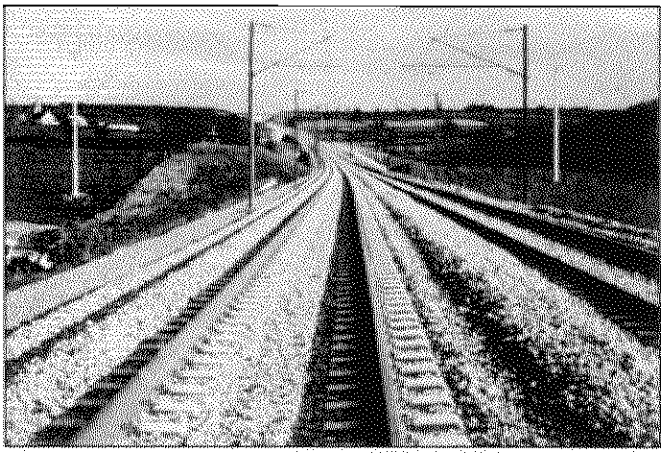

Fig. 1. Conventional ballasted track (TGV track, twin-block concrete sleepers)

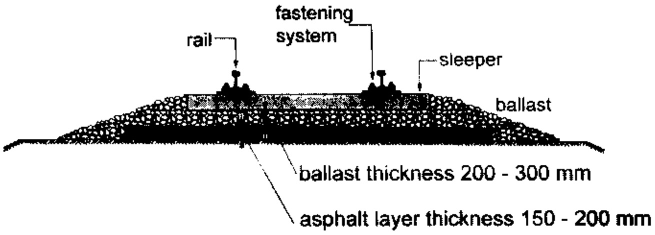

Fig. 2: Reinforced bituminous concrete layer

Ballastless track

In order to avoid the disadvantages of ballasted track mentioned above, a number of different types of ballastless track have been developed [2].

In addition to those already mentioned, there are also a number of other reasons for using ballastless track, such as:

- lack of suitable ballast material;
- the need to make the track accessible to road vehicles;
- a requirement for the track to emit (even) less noise and vibration, and to avoid the release of dust from the ballast into the environment.

While relatively expensive to build, ballastless track requires little maintenance, as long as it is built correctly. The advantages of ballastless track lie in its:

- reduced height;
- lower maintenance requirement and hence higher availability;
- increased service life.

If the low-maintenance characteristics of ballastless track on open railway lines are to be retained, great care must be taken to ensure that the subgrade layers are homogeneous and capable of bearing the loads imposed. The concrete slabs may be prefabricated or poured on site.

On bridges, where the concrete slabs effectively form part of the structure, the reduction in height is a major argument in favour of ballastless track. However, the absence of a ballast bed does mean that elasticity has to be created by other means.

Many different types of ballastless track are currently in use around the world [3], [4]. Only a small number of these have been specially developed for high-speed track, such as those in Japan, Germany, France and Italy. However, some ballastless track concepts originally designed for lower speeds could possibly also be applied to high-speed track.

Europe

Ballastless track is undergoing rapid developments in Germany. Since 1996, German Rail (DB AG) has been operating a test track in Karlsruhe which consists of seven new types of ballastless track [5], [6]. The best-known German designs are the Rheda and the Züblin [7], named after the places where these types were first used. In both these systems, the sleepers are cast into a concrete slab. Prefabricated variants have also been developed. Fig. 3 shows a transition between two prefabricated slab structures, in which the discrete supports (sleeper blocks) are cast into the slab.

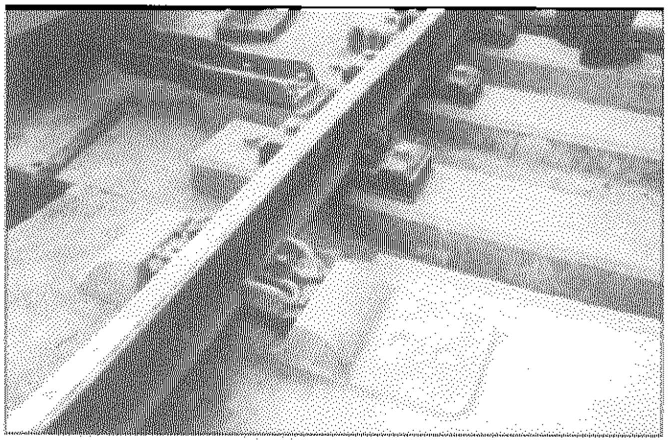

Fig. 3: Embedded concrete sleepers (transition between two prefabricated slab structures)

The Stedef system, illustrated in Fig. 4, is most often used in tunnels, with metro systems being the most common application. This technique, however, is also used on high-speed track. The rubber boot under the sleeper provides a high degree of elasticity, which in turn ensures good noise and vibration insulation [4].

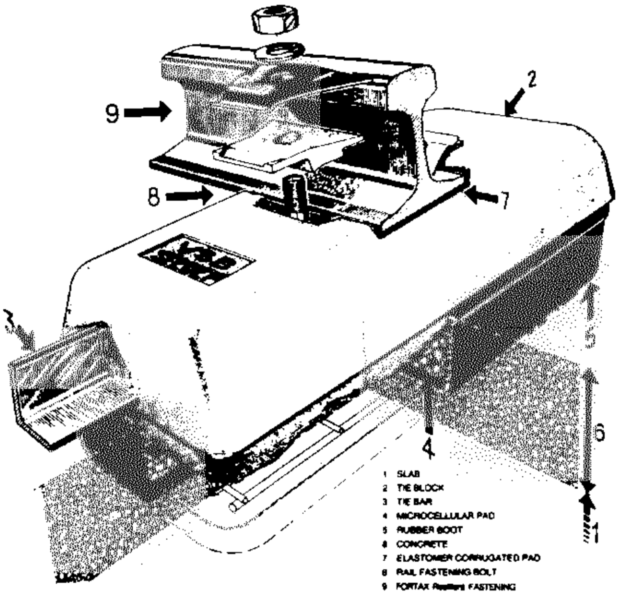

Fig. 4: Stedef twin-block concrete sleeper system

The Sonneville Low Vibration track, which is closely related to the Stedef system, is a block track design which, like the Stedef system, also makes use of a rubber boot. Applications of this system include the Channel Tunnel.

Another twin-block variant related to the Stedef system is the Swiss Walo system, which is mainly used in tunnels [8]. In this case, first a special slipform paver lays a concrete track base and installs a cable duct. Then the twin-block sleepers – fitted with rubber boots – are placed in position and cast into place (Fig. 5).

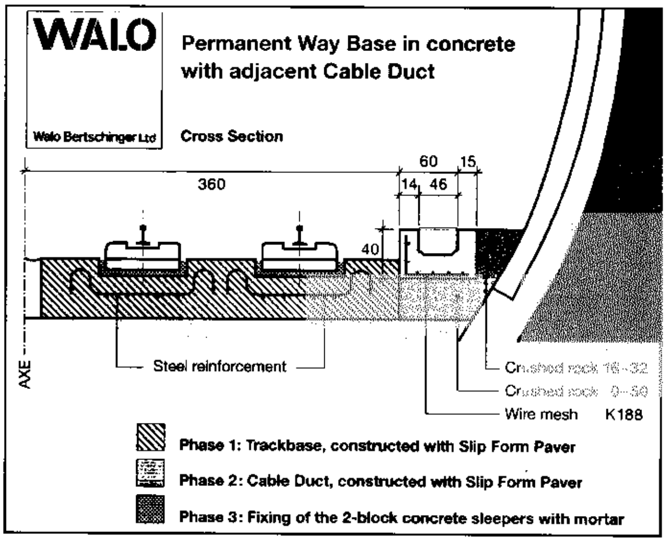

Fig. 5: Walo system

The Edilon Block System (Figs. 6 and 7), which is mainly used for bridges and tunnels, falls into the same category. When installing this 'top-down' system, first the rails and blocks are placed in position. Then the blocks are cast in using Corkelast, in order to provide the necessary elastic support. Important applications of this type of ballastless track include 100 km of NS and light rail track in The Netherlands, and approx. 100 km at the Madrid Metro in Spain.

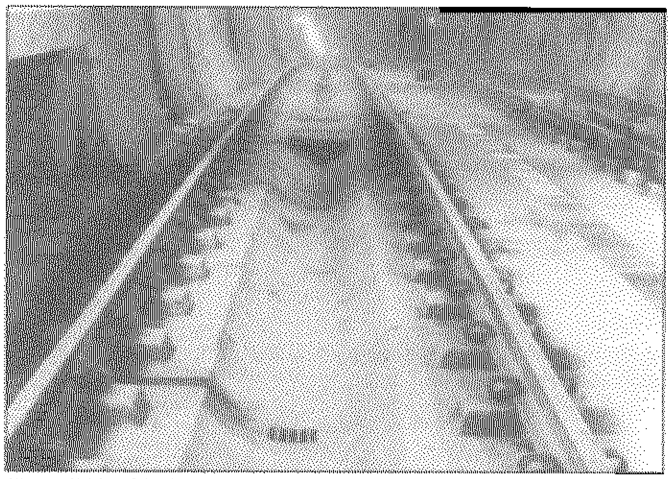

Fig. 6: Edilon Block System with DE fasteners

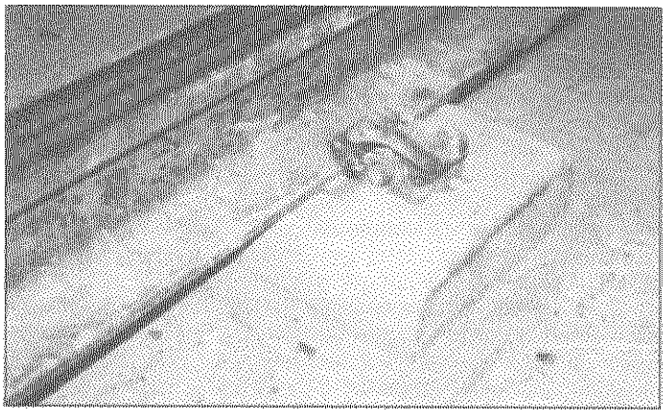

Fig. 7: Edilon Block System with Pandrol fasteners

Austrian Federal Railways (ÖBB) has 25 km of ballastless track, mainly in tunnels and on viaducts. The ÖBB-Porr system, comprising embedded monoblock sleepers enclosed in rubber, is very similar to the German Züblin design mentioned earlier. There is also a variant – the Porr system, which makes use of prefabricated slabs. In 1992, ÖBB set up a test section on the Wels-Passau line to test a ballastless track system designed for high speeds, known as Modurail. This system uses prestressed sleepers, which are elastically supported on concrete slabs [9].

In 1992, Italian State Railways (FS) had less than 100 km of ballastless track, 25.4 km of which located on the Rome-Florence high-speed line. This track, supplied by IPA, is based on the system used in Japan [10].

Japan

Japan is effectively the birthplace of high-speed rail. Development work on the Shinkansen network started at the end of the 1950s, and the first line (between Tokyo and Osaka) opened in Autumn 1964. Currently, five lines are in service and a sixth is under construction.

Government plans dating back to 1970 specify a national high-speed rail network consisting of 3,500 km of double track. By 1993, a good 1,400 km of this had been built, more than 1,000 km of which consisting of ballastless track. In Japan, ballastless track always consists of prefabricated concrete slabs, each just under 5 m long. The percentage of ballastless track varies considerably from line to line. The newer lines include a higher percentage (up to 96%). The ballastless track design has remained virtually unchanged since the first sections were installed in 1972.

The Shinkansen ballastless track [11], [12], [13] consists of a sub-layer stabilised by means of cement, cylindrical 'stoppers' to prevent lateral and longitudinal movement, reinforced prestressed concrete slabs measuring 4.93 m × 2.34 m × 0.19 m (4.95 m × 2.34 m × 0.16 m in tunnels) and bituminous cement mortar injected under and between the slabs. The slabs weigh approx. 5 t each (Fig. 8).

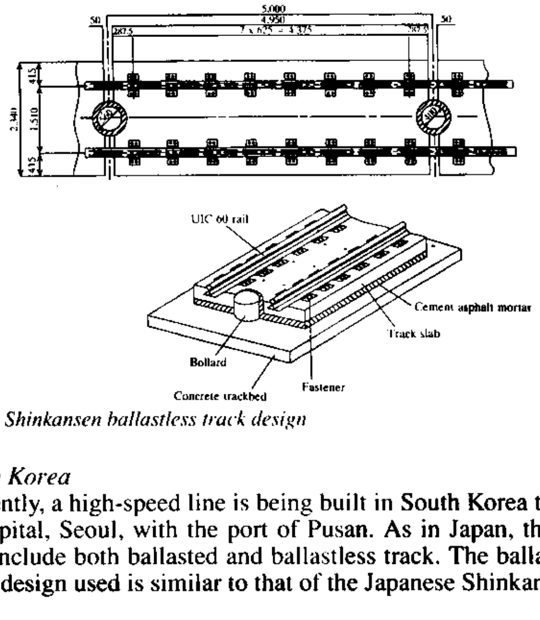

Fig. 8: Shinkansen ballastless track design

South Korea

Currently, a high-speed line is being built in South Korea to link its capital, Seoul, with the port of Pusan. As in Japan, the line will include both ballasted and ballastless track. The ballastless track design used is similar to that of the Japanese Shinkansen.

The embedded rail construction

All the ballastless track designs mentioned so far are based on the rail being supported at discrete points – the sleeper principle. Since 1976, a continuously supported rail system has been in use – on a small scale – in The Netherlands. This system, which is known as the Embedded Rail Construction (ERC), provides continuous rail support by means of a compound consisting of Corkelast, a cork/polyurethane mixture developed by Edilon B.V. (Figs. 9 and 10).

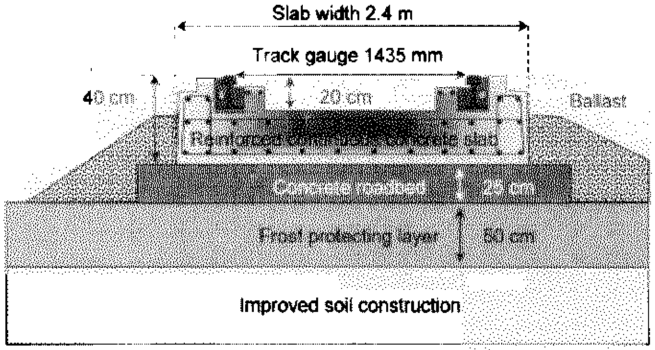

Fig. 9: Embedded Rail Construction

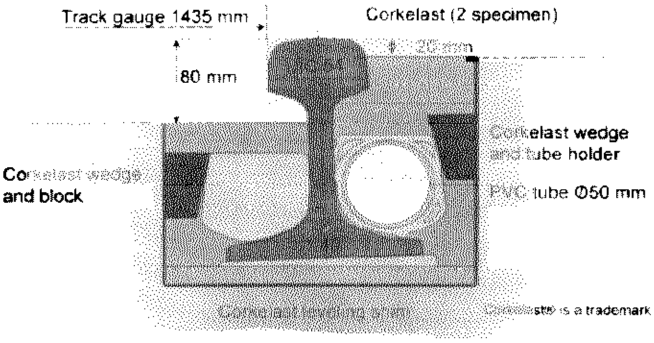

Fig. 10: Detail of Embedded Rail Construction

The great advantage of this design is that the track is built 'top-down', which means that tolerances in the supporting structure have no effect on the track geometry obtained. NS now has 20 years of experience with this system. It has proven to require little maintenance. The possibility is currently under investigation of using ERC as the standard track system for the high-speed line from Amsterdam to the Belgian border (HSL South). As part of this study, a 3 km test section will shortly be built at Oirschot, The Netherlands.

To a large extent, construction costs will depend on the manner in which this type of track is installed. It is assumed that the track will be based on a continuous reinforced concrete slab installed by means of a slipform paver (Fig. 11). Optimisation of this mechanised construction process is also one of the aims of the study.

Fig. 11: Slipform paver (Photo: [illegible])

Track resilience

On conventional track, approx. half the resilience needed to absorb dynamic forces is provided by the ballast bed and the other half by the subgrade. Ideally, the stiffness of the overall track structure should be in the order of 100 kN/mm, which is equivalent to a deflection of 1 mm under an axle load of 20 t. High-frequency vibration is filtered out by a rail pad inserted between the rail and the sleeper.

On ballastless track, and on bridges where the rails are fixed down directly, additional resilience has to be added to the system in order to compensate for the absence of ballast. In principle, there are two ways of achieving this:

- — by adding extra resilience under the rail, such as inserting extra thick rail pads or using ERC; or
- — by inserting a second resilient layer under the supporting blocks or the sleepers.

In the latter case, a two-mass spring system is effectively created, with a primary and secondary suspension, similar to that of a vehicle.

Conclusions

Conventional track, using ballast, has been the norm for a long time. Over the years, there has been a movement away from timber sleepers in favour of concrete. This is primarily due to the superior dimensional stability, longer service life and greater stability of concrete. Modern track with sleepers appears to be very suitable for high speeds and for heavy freight traffic. Low construction costs and ease of maintenance are essential, positive factors. In combination with a sound subgrade and reinforcing layers of, for instance, bituminous concrete, sleeper track will remain an attractive concept well into the 21st Century.

For new main corridors for high-speed and freight traffic, factors such as extended service life, low maintenance, availability and capacity for increased speeds and axleloads will gain in importance. Ballastless track designs offer certain advantages in this respect.

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