INNOVATIONS IN RAILWAY TRACK

Coenraad Esveld
Professor of Railway Engineering, TU Delft

This paper describes innovations in railway track structures. Special attention is devoted to alternatives for ballasted track, with emphasis on low-maintenance solutions, together with versatile high-speed track and heavy haul track for the 21st century.

P.O. Box 5048
NL-2600 GA Delft
The Netherlands

Tel: +31 418 516369
Fax: +31 418 516372
Email: esveld@ct.tudelft.nl

TABLE OF CONTENTS

LIST OF FIGURES

1. INTRODUCTION

Renewal is an integral part of existence itself, a rule to which railway infrastructure is no exception. Yet renewal goes beyond simply replacing worn-out track and components. Renewal involves keeping abreast of developments, both at home and abroad, becoming a part of them to bring about progress where required and putting that progress into practice.

Increasing traffic density is making it steadily more difficult to carry out track maintenance and renewal. On NS, night time possessions often last no longer than 5 hours, and on the future high speed link in Korea (a 435 km line from Seoul to Pusan) the maximum effective possession is estimated at no more than 1 ½ hours per night. Seen against this background, the current increase in the popularity of low-maintenance track designs is scarcely surprising, especially when we bear in mind the social pressure for sustainable construction.

2. BALLASTED TRACK

Traditionally, railway track has consisted of rails laid on timber or concrete sleepers, supported by a ballast bed. Fig. 1 shows an example of this traditional design – a TGV track with twinblock sleepers.

The main advantages of this traditional type of track are [1]:

- Relatively low construction costs
- High elasticity
- High maintainability at relatively low cost
- High noise absorption

However, ballasted track also has a number of disadvantages:

- 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, due to the limited lateral resistance offered by the ballast
- Ballast can be churned up at high speeds, causing serious damage to rails and wheels
- Reduced permeability due to contamination, grinding-down of the ballast and transfer of fine particles from the subgrade
- Ballast is relatively heavy, leading to an increase in the costs of building bridges and viaducts if they are to carry a continuous ballasted track
- Ballasted track is relatively high, and this has direct consequences for tunnel diameters and for access points

The rate at which the track deteriorates is closely related to the quality of the original construction, particularly the rail geometry, the homogeneity of the subgrade layers and the supporting capacity of the sub-ballast.

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

- Laying a ballast mat between the ballast bed and the bridge
- Increasing the elasticity of the fastenings

Figure 1 TGV track with twinblock sleepers

3. REINFORCING LAYERS

Softening of the subgrade can cause major problems, especially in combination with vibration. High speed lines in Japan and Italy are therefore laid on a waterproof asphalt layer between 5 cm and 8 cm thick. In order to distribute – and hence reduce – subgrade stresses this bituminous concrete layer can be increased to 15 cm or 20 cm (see Fig. 2). The high maintainability of the track geometry inherent in classic ballasted track is thus retained.

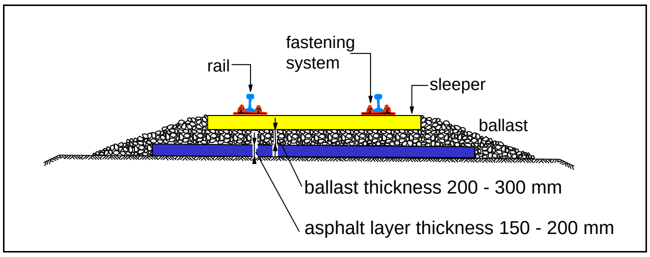

Figure 2 Reinforced bituminous concrete layer

Asphalt layers may offer major advantages in the construction of new track designed for relatively high axle loads 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 maintained.

4. BALLASTLESS TRACK

In order to avoid the disadvantages of ballasted track mentioned above, a number of types of ballastless track have been developed [4]. In addition to the disadvantages already mentioned, there are 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 track to cause (even) less noise and vibration nuisance
- Preventing the release of dust from the ballast into the environment

While relatively expensive to build, slab track requires little maintenance, as long as it is built correctly. On bridges, where the slab effectively forms part of the structure, the reduction in height is a major argument in favour of slab track. However, the absence of a ballast bed does mean that elasticity has to be created by other means.

The advantages of this more expensive type of track lie in its:

- Reduced height
- Lower maintenance requirement and hence higher availability
- Increased service life

If the low-maintenance characteristics of slab track on open line are to be retained, great care must be taken to ensure that the subgrade layers are homogenous and capable of bearing the loads imposed. The slabs may be prefabricated or poured on site. The high level of investment required has prevented widespread use of slab track on open line so far. However, one must look not only at the investment required but also at the total life cycle costs. The greatest savings in this respect will be achieved in tunnels and on bridges. The use of more efficient construction methods, of the type used in the road construction industry, could reduce construction costs still further.

Figure 3 Embedded sleepers; transition, two German slab track structures

5. USE OF BALLASTLESS TRACK

Many different types of ballastless track are currently in use around the world [10, 11]. 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 be applied to high speed track.

Ballastless track is undergoing rapid development in Germany. Since 1996, DB has been operating a test track in Karlsruhe consisting of seven new types of ballastless track [9, 19, 20]. The best-known German designs are the Rheda and the Züblin [15], named after the places where these types were first used. In both of 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. Although most applications involve bridges or tunnels, the use of ballastless track on open line is increasing.

The Stedef system, illustrated in Fig. 4, is most often used in tunnels. Metro systems are the most common application, but the technique is also used on high speed networks. A rubber boot under the sleeper provides a high degree of elasticity, which ensures good noise and vibration insulation [11].

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

Another twinblock variant related to Stedef is the Swiss Walo system (Fig. 5), mainly used in tunnels. A special slipform paver lays a concrete slab, following which the sleepers – fitted with rubber boots – are placed in position and cast into place. The Edilon block track system (Fig. 6, 7 and 8)) falls into the same category, and is mainly used for bridges and tunnels. Under this (top-down) system, the first step is to place the rails and blocks in position. The blocks are then cast in using Corkelast, to provide the necessary elastic

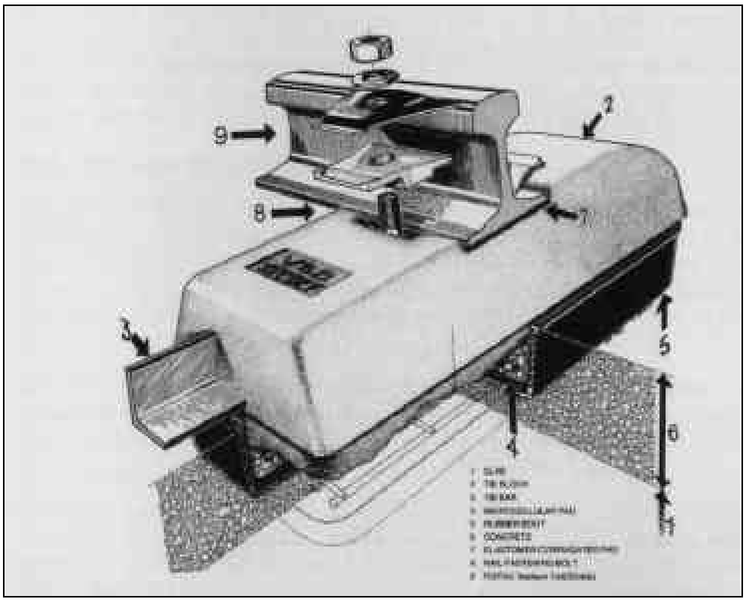

Figure 4 Stedef Twinblock track system

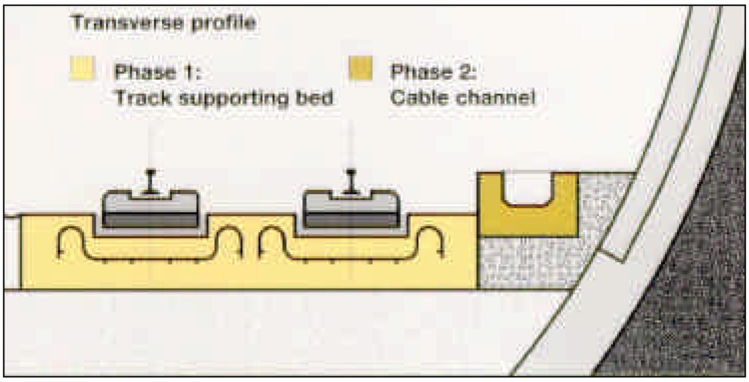

Figure 5 Walo system

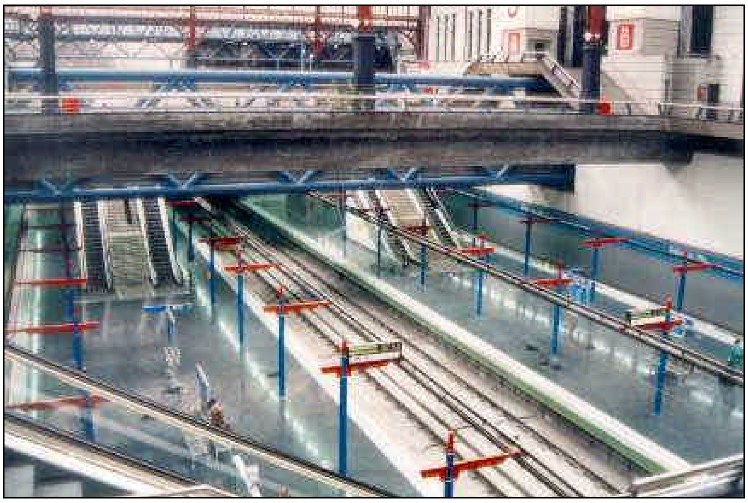

Figure 6 Edilon block track system at Madrid Metro

support. Important applications include 100 km on NS and light rail systems in the Netherlands and the Madrid metro (approx. 100 km).

Japan was 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. Five lines are currently in service and a sixth is under construction.

Government plans dating back to 1970 specify a national Japanese high speed network of 3 500 km of double track. By 1993, a good 1 400 km of this had been built (double track), of which more than 1 000 km consists of ballastless double track. In Japan, ballastless track always consists of prefabricated slab track, using slabs 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 slab track design has remained virtually unchanged since the first sections were laid in 1972.

The Shinkansen slab track [13, 16, 18], (see example in Fig. 9) consists of a sublayer stabilized using cement, cylindrical “stoppers” to prevent lateral and longitudinal movement, reinforced prestressed concrete slabs measuring 4.93 m x 2.34 m x 0.19 m (4.95 m x 2.34 m x 0.16 m in tunnels) and bituminous cement mortar injected under and between the slabs. The slabs weigh approx. 5 t.

South Korea is currently building a high speed line to link the capital, Seoul, with the port of Pusan. As in Japan, the line will include both ballasted and ballastless track. The ballastless track is based on the Japanese Shinkansen slab track.

Figure 7 Edilon Block System with DE fasteners

Figure 8 Detail of Edilon Block System with Pandrol fasteners

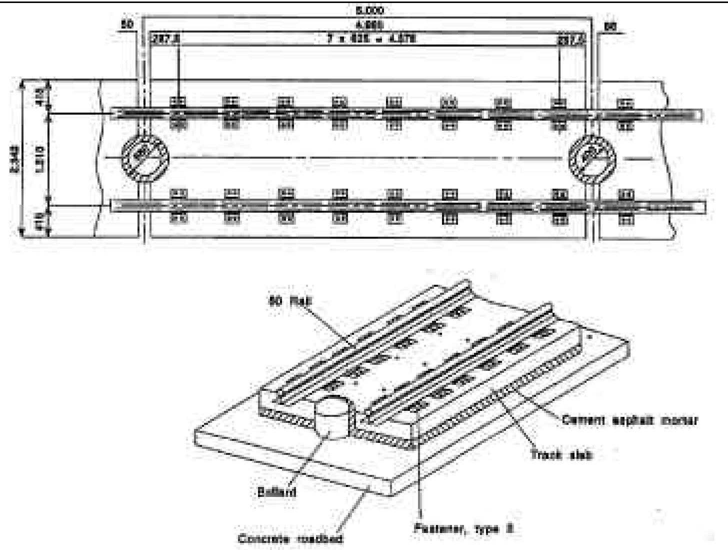

Figure 9 Shinkansen slab track

Ballastless track has been little used in Italy. In 1992, FS had less than 100 km of ballastless track, of which 2 × 5.4 km were located on the Rome-Florence high speed line. This track, supplied by IPA, is based on the Japanese system mentioned above.

ÖBB (Austria) 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 Züblin design mentioned above. There is also a variant using prefabricated slabs (the Porr system). A test section was set up on the Wels-Passau line in 1992 to test an ballastless track system designed for high speeds, known as Modurail. This system uses prestressed sleepers, elastically supported on a concrete slab [21].

All the designs mentioned so far were based on the rail being supported at discrete points – the sleeper principle. Since 1976, a continuously supported rail system has been in use in the Netherlands on a small scale. The system is known as the Embedded Rail Construction (ERC), and involves providing continuous support for the rail by means of a compound consisting of Corkelast (a cork/polyurethane mixture). 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 experience with this system, and it has proved to require little maintenance. The possibility is currently under investigation of using ERC as the standard track system for the HSL South from Amsterdam to the Belgian border. A 3 km test section is shortly to be built in Holland as part of this study. Fig. 10 illustrates the principles of this slab track system, while Fig. 11 shows the channel containing the embedded rail.

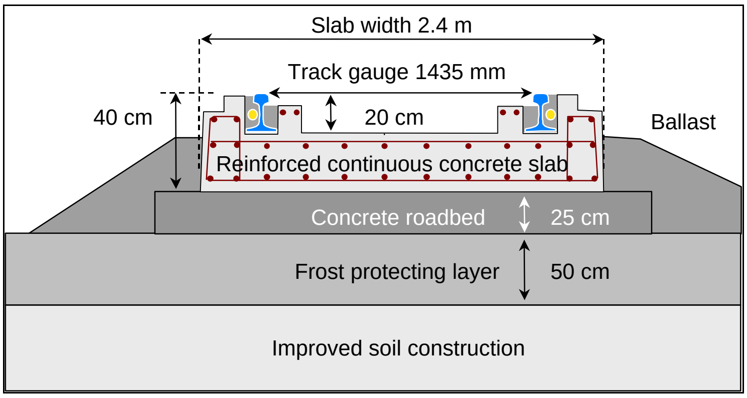

Figure 10 Embedded rail concept for 3 km test track in Holland

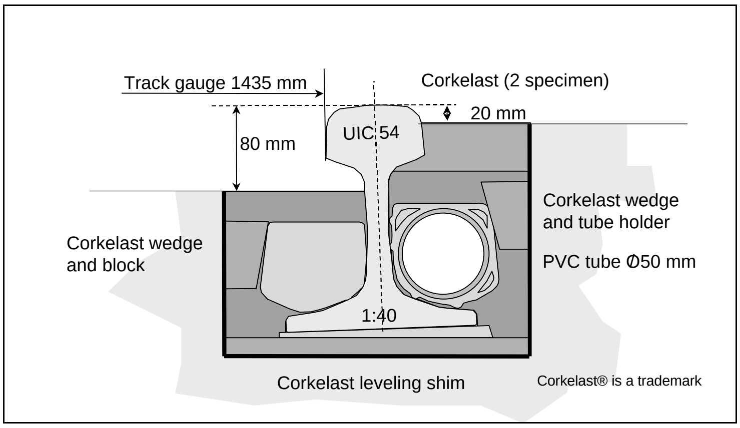

Figure 11 Details of embedded rail structure

Figure 12 Slipform paver

To a large extent, construction costs will depend on the manner in which this type of track is laid. It is assumed that the track is based on a continuous reinforced concrete slab laid using a slipform paver (see Fig. 12). One of the aims of the study is to examine and optimize this mechanized construction process.

6. TRACK RESILIENCE

On conventional track, approximately 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 of the order of 100 kN/mm, which equates to the structure deflecting 1 mm under a 20 t axle load.

High frequency vibration is filtered out by a rail pad inserted between the rail and the sleeper. This corkelast, or rubber component allows the use of relatively stiff concrete sleepers, which are susceptible to scratching.

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

- Adding extra resilience under the rail by, for instance, inserting extra thick rail pads (Fig. 13) or by using ERC
- Inserting a second resilient layer under the supporting blocks or the sleepers.

Figure 13 Elastic rail support in track structure, Berlin

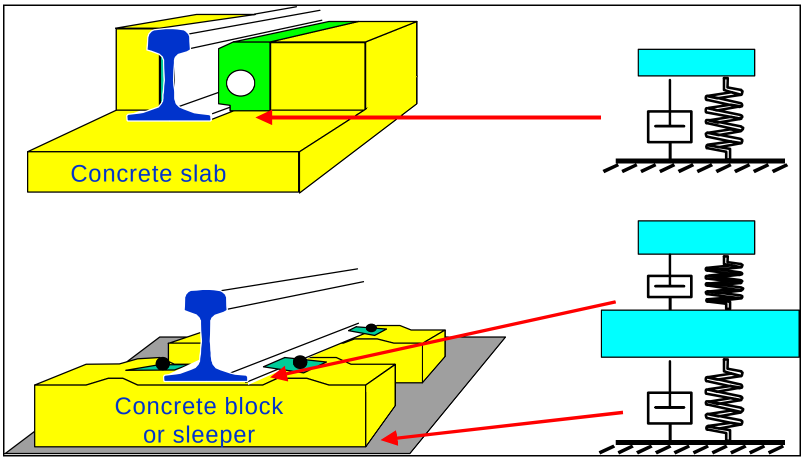

Figure 14 Principle of spring system in track

In the second case, a two-mass spring system is effectively created, with a primary and secondary spring, analogous to a vehicle. Fig. 14 shows the principle. TU Delft is currently studying the difference in the dynamic behaviour of these types of track

7. CRITICAL TRAIN SPEEDS

An important issue related to high-speed train operation is the propagation speed of surface waves, which governs the critical train speed [3, 5, 6, 7]. These Rayleigh waves propagate at a speed approx. 10% lower than that of shear waves, their propagation speed being given by:

$$c_T = \sqrt{\frac{G}{r}}$$

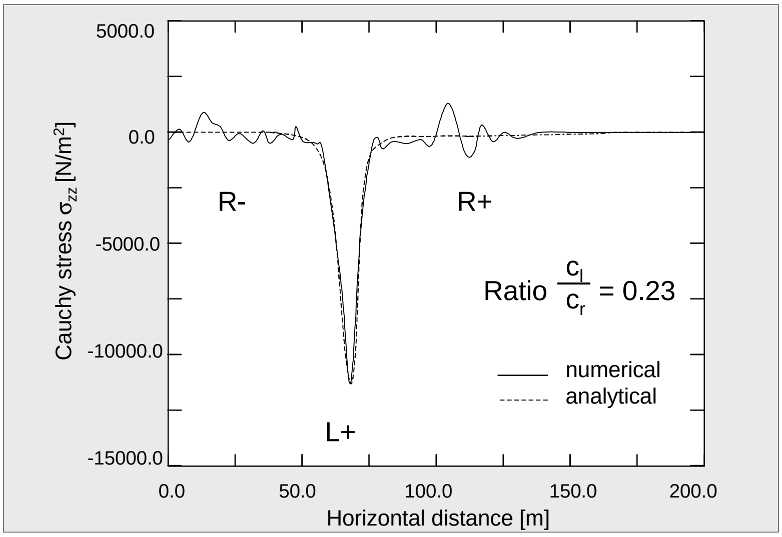

Figure 15 Stress σ_{zz} at z=5.68 below the surface, after 10 m of wave propagation

in which *G* is the shear modulus and *r* is the density. As an example, Fig. 15 shows the vertical soil stresses at 5.68 m depth under a moving load. Rayleigh waves are propagating in both positive and negative direction [6]. For sub-critical speeds the displacements underneath the load are more or less symmetrical with respect to the load and the maximum coincides with the location of the load [5]. If the travelling speed is higher than the critical speed the maximum is behind the location of the load (Fig. 16). However, to pass the point of critical speed would lead to large amplifications, which are unacceptable for railway practice, this being the reason that present railway operations are all sub-critical. Wave propagation is also an important issue at transitions such as between bridge and plain track. A gradual stiffness transition is desired to confine dynamic amplification [11].

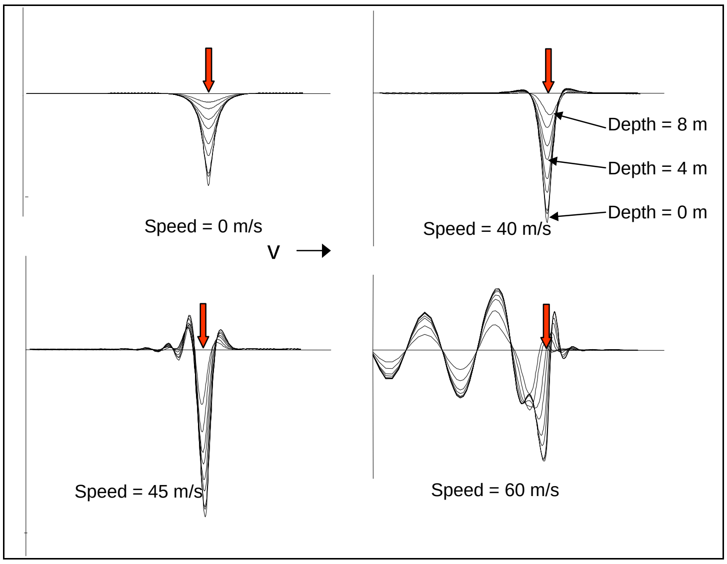

Figure 16 Displacements at sub and super critical train speed

Especially in delta areas, such as in the Netherlands and in Japan, the subgrade often consists of weak soils with critical speeds far below the intended operational speed. In such cases measures for increasing the vertical stiffness are unavoidable. Possible solutions include soil improvement, deep mixing, grouting and piles.

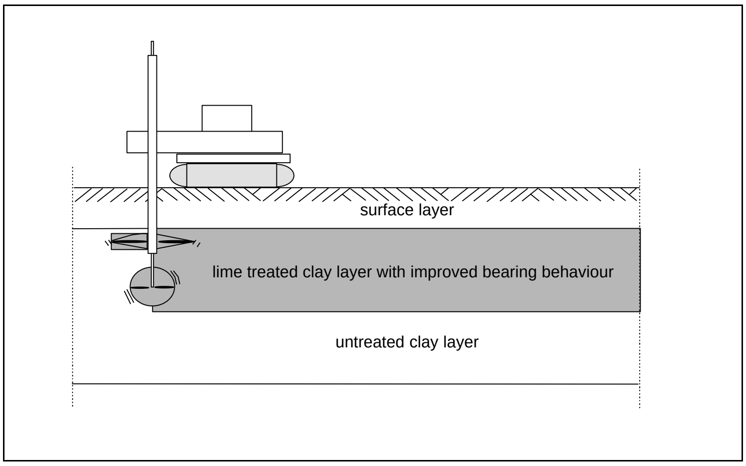

Figure 17 Principle of soil improvement by lime treatment

Fig. 17 illustrates the principal of lime treatment for large-scale stabilization of the subgrade. Stabilization using grouting or deep mixing can be applied to the soil very precisely. Grouting involves injecting liquid mortar (based on cement or limestone), which then hardens, while deep mixing consists of mixing the material already present with a liquid or dry mortar based on cement, limestone, fly-ash etc. In Japan, considerable experience has been built up of the application of this technique, especially where dwellings and business premises have to be made earthquake-proof. Projects of more relevance to the Dutch situation include highway projects in Scandinavia [14] and Italy, which have shown that it is possible to achieve a considerable improvement in supporting capacity and a reduction in the subsidence of various thick layers that are incapable of supporting loads.

A study is currently underway into the possibility of improving the soil by means of deep mixing for the HSL South, much of which is to be built on very soft ground. The alternative would be to lay the entire slab track on piles. Whichever system is adopted, simply using slab track will significantly increase vertical stiffness and, therefore, the critical speed.

In any case, critical speed should be increased to a level at least 50% higher than the operational speed, particularly when anticipating future speed increases.

8. TRANSITION BETWEEN PLAIN TRACK AND BRIDGE

Experience has shown that the transition between bridge and plain track often causes problems (see Fig. 18). Immediately after the track is laid, in particular, the plain track is subject to relatively high subsidence, at a rate different to that of the bridge. These transitions have been shown to cause problems, both in theory [6, 8] and in practice.

The change in stiffness causes increased dynamic forces, the extent of which is determined by speed, stiffness ratio, damping and the length of the transition. In [6] a study is described into the effects of changes in vertical stiffness on the dynamic response. Figure 19 defines the stiffness transition between a soft soil (clay) and a stiff soil (sand), with a linear stiffness transition of length L. Figure 20 shows the dynamic amplification factor for two situations. If the ratio between load speed and Rayleigh speed is low an asymptotic D.A.F. value of 1.21 is reached after a relatively short length of about 8 m. If the speed is close to the critical speed a much larger asymptotic value of 2.51 is found, which is reached at a transition length beyond 25 m. So it obvious to stay far from the critical speed. The change in track geometry resulting from subsidence also causes increased dynamic forces

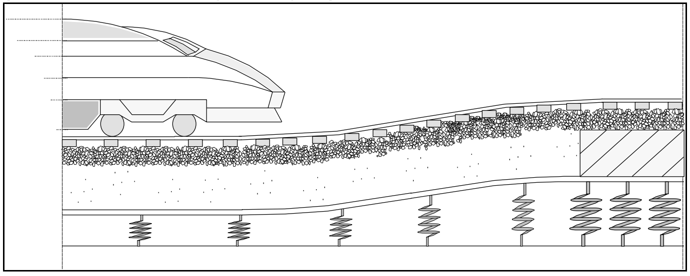

Figure 18 Principle of train response at a transition

Like large changes in subgrade stiffness, changes in the vertical alignment of the track lead to increasingly pronounced vertical accelerations in the vehicle, which may mean that the criteria for passenger comfort or maximum dynamic track force are no longer met. A marked increase in forces leads to accelerated deterioration of the track geometry and hence to additional maintenance.

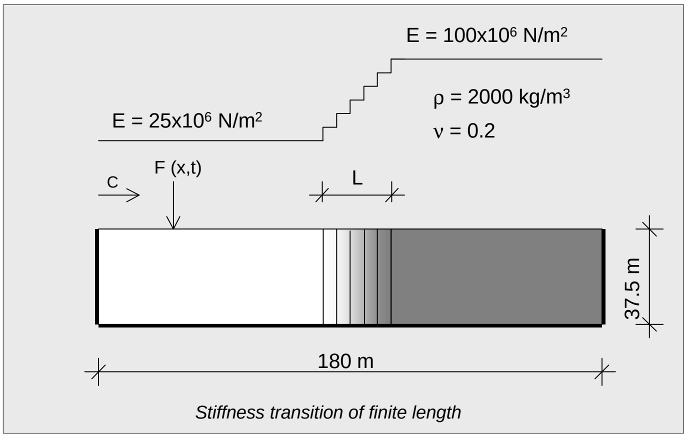

Figure 19 Stiffness transition of finite length

As part of its research into the problems of high speed rail systems, TU Delft has carried out a number of studies into the dynamic effects at the transition between bridge and plain track. These have revealed that the effects of a change in height are generally more significant than those of a change in stiffness. Fig. 21 shows an example of the car body accelerations calculated for a discrete event (change in height) of 30 mm, over a length of 30 m. Parametric studies have been carried out on the basis of the model described in [8], enabling accelerations and vertical wheel loads to be derived for various lengths of event and changes in height, at 300 km/h. Fig. 22 shows the differences in height that are acceptable for HSL stock for a given length of event, on the basis of a maximum permissible dynamic wheel force Q_{dyn} of 170 kN and a vertical car body acceleration a_v of 1.0 m/s^2.

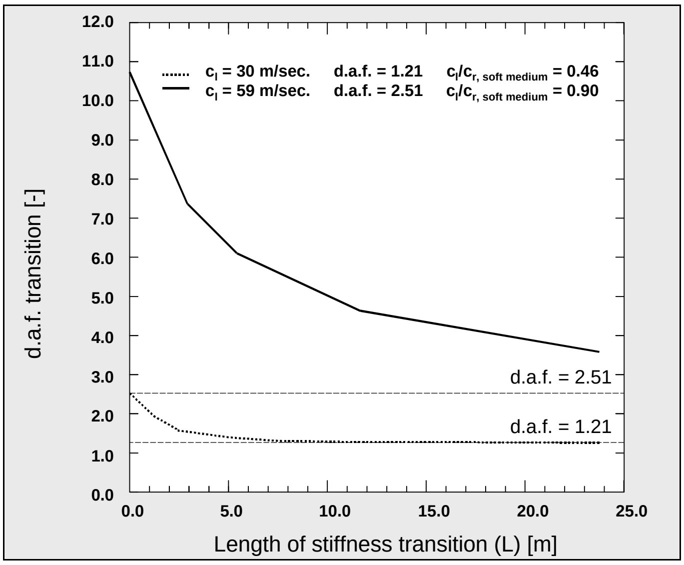

Figure 20 Dynamic amplification within the stiffness transition

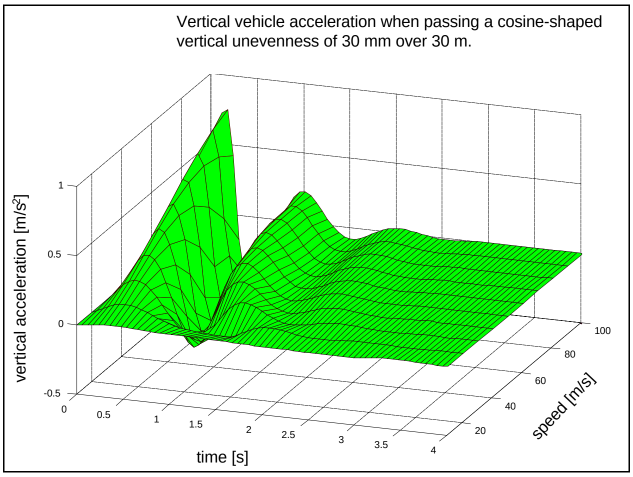

Figure 21 Calculated car body acceleration amplification at transition

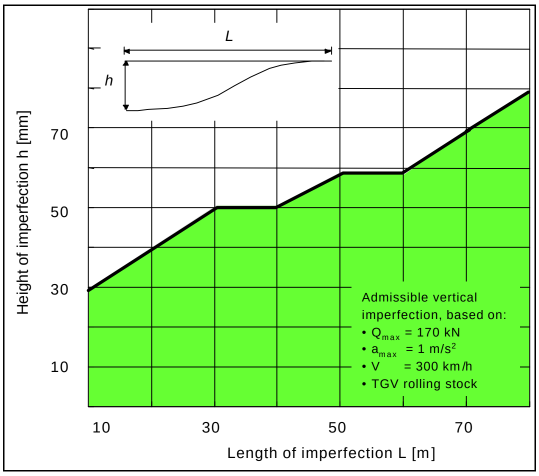

Figure 22 Design graph for transition structure based on admissible forces and accelerations

9. CONTROL OF TRACK MAINTENANCE

For the control of track maintenance and renewal it is essential that measurements and inspections be carried out at regular intervals. Nowadays most railways use recording cars for measuring track geometry and ultrasonic inspection systems, both for safety, and to facilitate planning of rail and track renewals.

Increases in speeds and forces are imposing ever tighter restrictions on the permissible deviations in track geometry. This means that measurements have to be highly accurate. it is extremely important so to formulate the specifications for the track structure that the parameters concerned can readily be measured and verified. This applies not only to the construction tolerances but also to the maintenance standards.

The deterioration process to which the track is subject has to be monitored frequently in order to allow prompt intervention before irreparable damage is caused. An objective assessment of track quality and optimum use of maintenance capacity require that all available data be stored in a database (a management information system).

Please see [1, 2] for further details concerning track maintenance.

10. 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 concrete's superior dimensional stability, longer service life and greater stability. 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 axle loads will gain in importance. Ballastless designs offer a number of advantages in this respect. Admittedly, the level of investment required is relatively high, but total life cycle costs will become increasingly important. The reduction in the cost of building a bridge that such a system can allow should not be ignored.

Building high speed track on soil as unsuitable as that of the western Netherlands will, in any case, require a great deal of effort to be expended on stiffening the subgrade in order to prevent problems with wave propagation and the critical train speed. A low-maintenance slab track is a logical element in a concept aimed at ensuring sufficient vertical track stiffness.

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