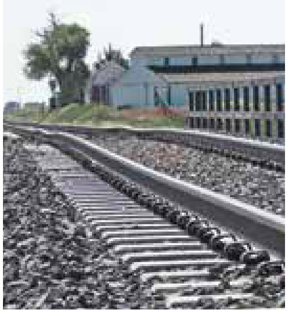
Railway Gazette

INTERNATIONAL



TRACK MAINTENANCE

Life-cycle costs

Understanding and addressing the mechanisms of track deterioration

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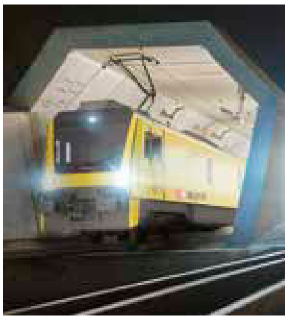

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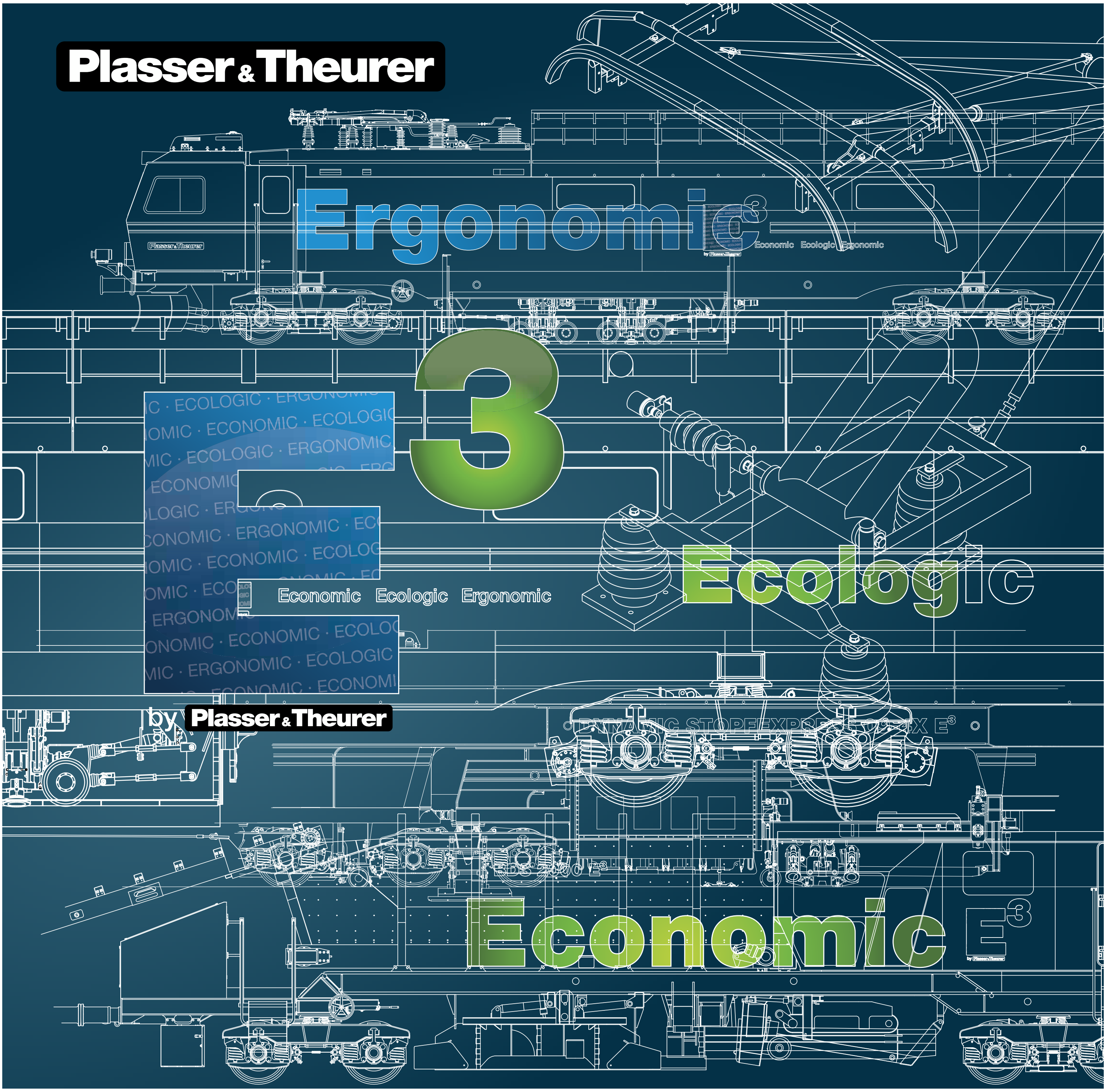

Managing **track stiffness** in transition zones

Even in an era of highly mechanised maintenance, transition zones still require particular attention to manage variations in track parameters caused by the change in substructure. Tailoring the resilient elastic support to specific locations through finite element modelling can improve track quality and reduce costs for infrastructure managers.

Photo: Regis Chessum

SNCF Réseau has been investigating the degradation of track geometry in the transition zone from slab to ballasted track on LGV Est.

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As the proverb goes, a chain is only as strong as its weakest link. This applies equally to a rail network, as the track maintenance interval is determined by the condition of the most sensitive section. Typically this will be a transition zone, where interruptions to the continuous support provided by the substructure and trackbed alter the stiffness of the track (Fig 1).

Transition zones occur at the interfaces between slab and ballasted track, or where plain line traverses a built structure such as a bridge, tunnel or culvert. Discontinuities may also occur in trackforms of the same type. For example, if higher demands for vibration protection in residential areas require the use of a ballasted track with soft, vibration-isolated sub-ballast mats, this will create transition zones at the interfaces with the standard track, posing a track design and maintenance challenge.

The transition zone problem

Due to the varying degrees of stiffness and the associated deflection differences, an abrupt change in track parameters from one type of superstructure to another can result in increased dynamic stress. A rail vehicle has to cross a step, which, depending on its height, can lead to sudden increases in the wheel-rail forces (Fig 2).

Across a transition from ballasted to slab track, ballast settlement as a result of movement and wear is unavoidable. It is therefore necessary to tamp the track at regular intervals to prevent the emergence of voids and hollow areas underneath the sleepers. Maintenance intervals will depend on train speeds and the dynamic stress that is exerted.[1]

Because of its solid design, slab track exhibits much less or sometimes no settlement, resulting in the running surface of the ballasted track becoming lower than that of the adjacent slab track. When combined with a local change in stiffness, the resulting height difference places a

Fig 1. Changes in parameters at the transition zone create a discontinuity in the track.

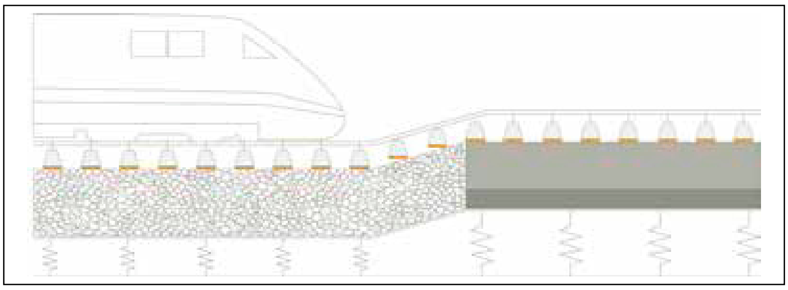


Fig 2. Defects occur at a transition zone from ballasted to slab track.

significantly increased dynamic stress on the track structure. This can generate excessive loads around the rail seats.

Indications of wear intensify as time goes by. These include white spots due to excessive abrasion of the ballast, settlement caused by high specific loads and short-pitch corrugation on the rail surface (Fig 3). Hollowness and voids underneath the sleepers can result in overloading, with potentially serious consequences such as broken rail clips, bolts and sleepers, or even rail fractures.

Any short pitch corrugation that forms in the transition zone can be seen as a phenomenon arising from the widely differing natural frequencies of the different superstructures. These are the result of varying excitation mechanisms that are caused by high dynamic forces.[2]

Higher costs

Maximising network availability is the top commercial priority for infrastructure managers. Transition zones only account for a fraction of network length, but incur a disproportionate share of maintenance outlay. Each year, North American railroads spend around $200m to maintain them, while in Europe the figure is in the region of €85m. Data from the Netherlands, for example, show that transition zones require between two and four times the expenditure of plain line sections[3], while other railways suggest a factor of eight.

This financial impact means that there is a clear incentive for asset owners to optimise the methods they use to treat individual transition zones, as even the most advanced track design and support options would recoup their costs very quickly. Depending on axleload and speed, the main criteria that infrastructure managers need to address are:

- reducing dynamic effects at local changes in track stiffness;
- adjustment of existing stiffness differences in the track;
- lowering settlement, especially in the transition zone, to fixed constraint points;
- defining the optimal length of a transition zone for efficient maintenance.

In most cases conventional ballasted track is too stiff and has to be joined to softer zones, such as a slab track segment with highly elastic rail seats. This raises the question of what differences in deflection or stiffness should be permitted in the transition zone, and over what distance the transition should extend.

Various guidelines have been established over the years. It is often recommended that the stiffness change is such that the computed deflection difference between the individual sections is no more than 0·2 mm to 0·5 mm. As far as the length of the transition zone itself is concerned, an engineering rule of thumb can be applied: the overarching aim is to make the transition as long as necessary (benefit) while keeping it as short as possible (cost). Depending on the case, a 0·5 sec, 0·7 sec or 1 sec duration is frequently specified, based on the length of time a train takes to cross it. However, short structures and high speeds would require very long and expensive transitions. A compromise therefore has to be found. Furthermore, the transition zone should never be shorter than the distance between the vehicle bogies.[4]

Established approaches

Transition zones have long been recognised as particularly sensitive elements, and numerous approaches have been adopted to alleviate the problem. But existing methods have significant downsides, sometimes making track maintenance more difficult or expensive.

Typically, track engineers seek to distribute the local discontinuity in the track parameters across a wider area. The change in stiffness should be carried out continuously, or in small steps, in order to minimise the dynamic stress on the superstructure. This essentially splits the transition into several sections.

On high speed lines, transition zones can extend over six sections or more. But this approach represents the high end of the spectrum, and typically requires a variety of measures usually including guardrails, ballast bonding, or transition slabs (Fig 4). While this method has been honed in the light of experience over many years, it is probably too complex for the majority of transition zones on conventional lines. Simpler options are often used to lower the cost, but these normally address only part of the problem.

The defined use of elastic superstructure components based on polyurethane could provide an additional or alternative mitigation method. The properties of this material allow the stiffness of the

Fig 3. Signs of wear in the transition zone: white spots (top right), short pitch corrugation (centre right) and track settlement in the ballast (below).

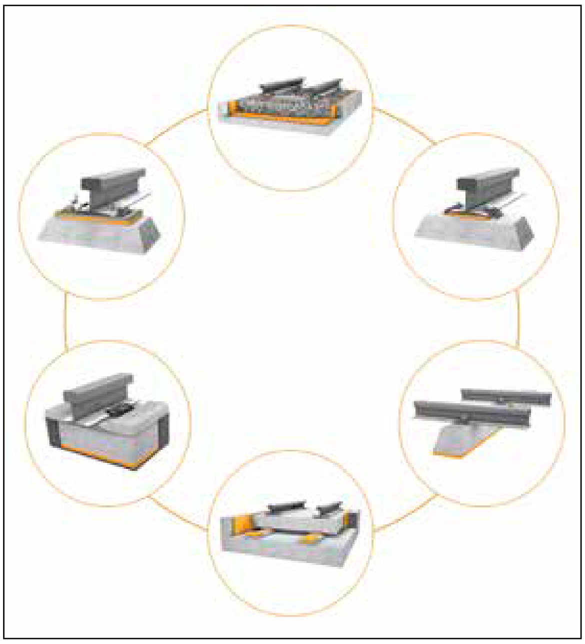


Fig 5. Various elastic products can be used to manage the track structure through a transition zone.

Fig 4. Guard rails along the transition (above). Bonding as a way of stabilising the ballast (right).

superstructure to be defined very precisely in terms of its elastic properties, while its complementary relationship with the ballast provides protection in the long term using the material's plastic properties.

Defined elasticity

The use of high-quality elastomers enables undefined levels of stiffness to be replaced by defined ones. The deflections in the individual sections of a transition zone can then be modified in a targeted manner. Depending on the track structure, changes to the stiffness can be made using rail pads, baseplate pads, under-sleeper pads, sub-ballast mats, mass-spring systems or elastic insert pads for sleeper boots (Fig 5).

In contrast to rubber-based materials, products such as Sylomer and Sylodyn use no softeners that might diffuse during the lifetime of the material. To all intents and purposes, the stiffness remains constant and defined for their entire service life.

Both materials can be tailored to offer either highly dynamic properties or highly plastic ones. When used for rail pads and baseplate pads, the ratio between dynamic and static stiffness is critical. Plasticity is out of the question. On the other hand, plastic deformation is a desirable attribute in other situations, such as where under-sleeper pads are used for ballast protection. Here it increases the contact area and significantly lessens the contact pressure between the ballast and the sleeper. The interlocking of ballast stones with the pad also reduces settlement and leads to less ballast movement, improving the stability of the overall track structure.

The adaptability offered by polyurethane allows for a broad range of products to be developed with finely graded degrees of stiffness and material properties. This means the materials can be precisely aligned to match the varying track parameters through each section of a transition zone. A further advantage of polyurethane is the positive impact on settlement. The top ballast layer is stabilised by becoming embedded in the pad, and vibration is reduced which in turn reduces the ballast movement. The critical frequency range within which stones in the ballast layer wear more quickly begins at an excitation of around 30 Hz. Any reduction in vibration amplitudes in this frequency range increases the service life of ballasted track.

Learn from experience

The fitting of additional elastic elements, such as under-sleeper pads, rail pads or baseplate pads, can be achieved without rebuilding the entire superstructure. Fig 6 shows a typical example of a bridge on the Ferrocarriles Suburbanos network in Mexico City. A section of ballasted track had been connected to a slab in the normal way. As no particular attention had been paid to this transition zone, the characteristic white spots associated with ballast abrasion became apparent very quickly. High dynamic forces then caused loosening of the fastening bolts and the surface of the slab track was damaged.

To try to resolve the problem, calculations were carried out to identify the most suitable elastic support products, which were then carefully matched with one another to create a smooth transition zone. To compensate for the unevenness of the damaged slab track, bespoke plastic adjusting plates made from Sylomer were fitted between the rail seat and the concrete. The pads

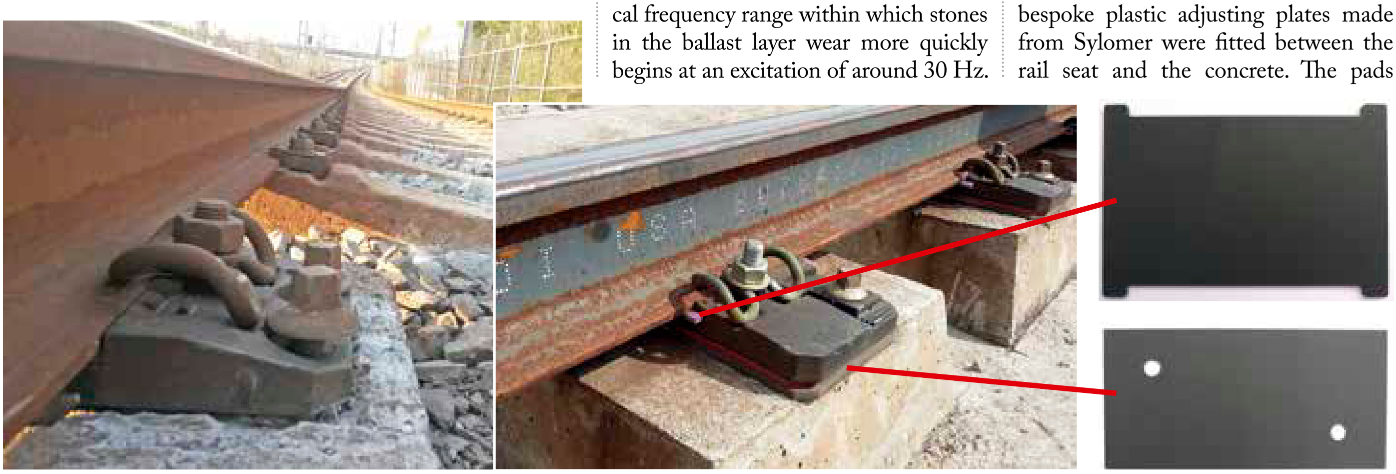
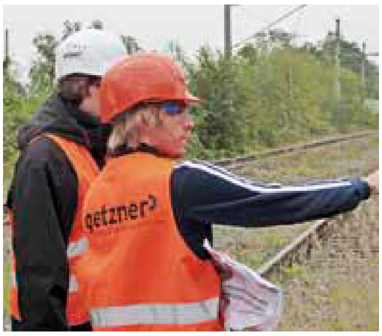


Fig 6. Damage to slab track with loosened fastening bolts (below) can be resolved by installation of plastic compensating plates and elastic rail pads (centre, right).



placed directly under the rail foot are made from softer, elastic Sylodyn. This ensures good load distribution and dynamic properties. In the transition zone, 25 sleepers were padded with elastoplastic Sylomer, which markedly reduced settlement. In combination, these measures considerably reduced wear at the transition zone.

It is always desirable to incorporate preventive measures when the track is first laid. For example, on a private coal railway in Germany, a transition zone was managed through a transition slab. To increase the contact area between the ballast and the transition slab, a newly-developed plastic sub-ballast mat was used for the first time. The contact area achieved during in-house laboratory experiments was around 34%, a figure that reduces the load between ballast and transition slab by a factor of six to eight. This stabilises and protects the ballast in the transition zone.

In-situ measurements aimed at verifying the transition calculations were carried out in autumn 2014 and are being repeated this summer. The experience gained from these measurements is being fed back into our development of a computer model to ensure our elastic support products can be tailored precisely to any given transition zone (below). ■

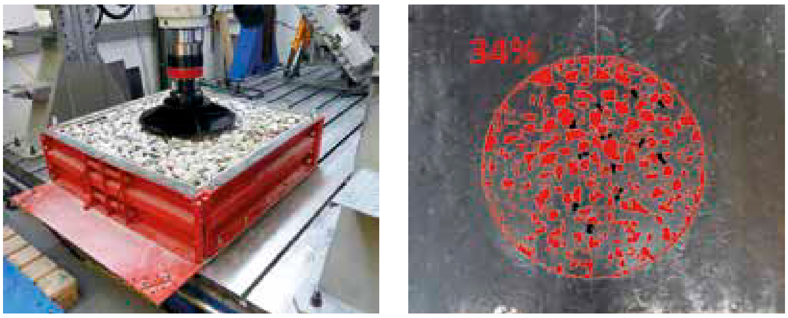


Fig 7. Deflection measurements at the transition under heavy haul conditions (top row). Determining the contact area in the lab (bottom row).

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ANALYSIS

Advanced modelling aids design

Most computer models calculate rail deflection using analytical methods such as the Zimmermann method — an infinitely long, continuously-bedded beam. These models have been verified many times and, in a homogeneous environment with constant track parameters, deliver extremely high quality results. However, when computing the critical points in the transition zone where there is a sudden increase in stiffness, the model reaches its limits.

Finite Element Modelling provides a means of computing the transition zone as a whole. Separating the model into a finite number of elements enables us to analyse each section as well as the points of discontinuity.

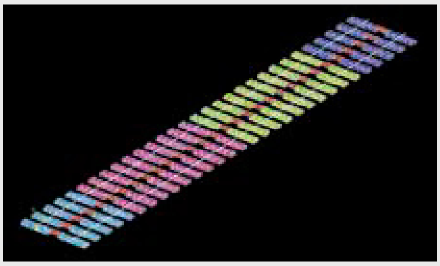
The structure of the FEM model consists of a number of elastic elements. Depending on the application, differing materials can be extruded in layers underneath the sleeper. This accounts for the bedding of both the ballast and the substructure, as well as that of the elastic elements such as sub-ballast mats and under-sleeper pads. In practice, the sleeper is tamped underneath the rail seats. Therefore the centre part of the sleeper has been cut out in order to create a realistic scenario (Fig 8).

Elements such as baseplate and rail pads can be added separately to the model to simulate the structure of a particular rail seat. Empirical material data, derived from laboratory measurements, have been stored for all the elastic elements used in the model. This allows us to account for the non-linear material properties. Bespoke elements, such as guardrails or transition slabs, can also be included.

In addition to rail deflection, the static and dynamic models provide other useful data, including rail foot tension, sleeper torsion or supporting forces.

Fig 8 shows how the deflections in the differing sections of track merge uniformly after optimised modelling. The reduction of load in the supporting forces at the transition point is evident, and although additional force peaks occur at the ends of the individual sections, they are much smaller than those occurring prior to FEM modelling.

Fig 8. FEM model (below), showing the resulting maximum rail deflection (right) and maximum force on rail supports (below right).



There is a direct correlation between the load on the superstructure in the transition zone and the quality of the design. The targeted use of non-linear material data enables various elastic beddings to be compared and the best option selected to minimise the stress placed on the track structure in the transition zone. ■