



The significance of track resilience

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The interaction between vehicle and track dynamics plays an essential role. The dynamic behavior and, more specifically the interactive forces, are directly related to the stiffness of the structure and its components. The reciprocal value of stiffness is flexibility or resilience. In general, one could state that enhancing the resilience, i.e. lowering the stiffness, has a positive effect on the dynamic forces. Of course one should be careful with that statement, as dynamic interaction is frequency dependant, in which not only stiffness, but also mass and damping play a role.

The excitations as such are mainly due to irregularities in the wheel rail interface, with wheel and rail irregularities being the most important elements. Low frequency excitations are associated with long waves in the track, which interact with the secondary spring stiffness of the bogie and the car body mass. The shorter the wavelength, i.e. the higher the excitation frequency, the more aggressive the dynamic forces. In the track, these high frequency loads are caused by rail corrugation, poor weld geometry and rail defects like spalling, wheel burns and squats.

Wheel geometry irregularities such as wheel flats, unroundness, polygonization and spalling have the same effects. It is important to limit these kinds of deviations in practice to confine dynamic impact and damage to the track components. For decision making on admissible deviations in rail geometry, new theories were developed at Delft University of Technology^{1,2}. To measure these kinds of irregularities in practice, the RAILPROF electronic straightedge, amongst other things, was developed³.

Automatic processing of data for decision support can be facilitated by systems like RAMSYS⁴.

In classical ballasted track, the resilient parts are primarily provided by the ballastbed, for the low frequencies (secondary suspension) and the rail pads for the high frequencies (primary suspension). Concrete sleepered track behaves stiffer than track with wooden sleepers and therefore rail pads for concrete sleepers are more critical.

The standard rail pad in Holland is the polyurethane cork rubber pad Fc9. Properties are given in Figure 1. For further details please refer to the dissertation of A.P. de Man⁵ and the book Modern Railway Track⁶. In Figure 2, a comparison between various

pad types is presented. This information is taken from page 223⁶. It should be emphasised that the real dynamic stiffness values are often substantially higher than the static stiffness values. In areas where ballast and formation problems exist, it is advised to use high elastic pads such as Fc9 or Fc584, or pads with similar properties in stiffness and damping.

With slab track the situation is even more critical, as in this case the ballast spring is lacking and all the resilience should be provided by the rail pad, in both the low and high frequency range. This is valid for both point supports, like

Code	All at $P_x = 20$ kN (first loading)	K [MN/m]	C [kNs/m]	f_r [Hz]	M_c [kg]	Z [%]	H [-]
Fc9	Railpad 4.5mm for UIC54 (new)	1387	33.1	1167	26.5	8.6	0.18
Fc9	Railpad 4.5mm for UIC54 (worn)	2127	44.9	1366	29.5	9.1	0.18
Fc9	Railpad 8.0mm for UIC54 (worn)	1191	38.4	1054	27.8	10.6	0.22
Fc9	Railpad 4.5mm for NP46 (worn)	1702	36.3	1248	28.1	8.3	0.17
Fc9	Railpad 4.5mm for UIC60 (new)	1611	31.7	1210	28.0	7.5	0.15
Fc9	Railpad 6.5mm for S49 (new)	1095	30.0	1030	26.1	8.9	0.18
Lupolen	Railpad 5.0mm for S49 (new)	4005	24.8	1672	36.3	3.3	0.07

Figure 1



	Soft	Normal	Hard	EVA
Type	(Fc584)	(Fc9)	(Fc846)	
Stiffness k [kN/mm]	970	1420	2990	3032
Damping c [kNs/m]	32	34	29	29

Figure 2

in Rheda type slab tracks, as for the embedded rail with a continuous support. For Rheda slab track in high-speed lines, a point of stiffness of the support is required between 25 and 35 kN/mm. Under an axle load of 170 kN for high-speed trains, and assuming that 50% of the wheel load is transferred to the support, i.e. 25% of the axle load, then this support load amounts to 42.5 kN. The corresponding vertical displacement therefore amounts to 1.7mm-1.2mm. From practical experience on the wheel rail interface, it appears in practice that the maximum vertical deflection should be limited to 2mm.

From a simple dynamic analysis, the relationship between the dynamic pad force *F* and the pad stiffness *k* can be derived as:

$$F = Constant * \sqrt{k}$$

This means that if the pad stiffness is lowered by a factor of two, the dynamic force is reduced by 30%.

In ballasted track, two other elements of resilience can be installed. A classic one is the ballast mat underneath the ballastbed. This is performed mostly for mitigating the propagation of ground vibration. On viaducts, mitigating of structure-borne

noise is sometimes an issue, but here another aspect is also relevant and that is the prevention of ballast particle cracking and in this way improving the durability of the track quality.

The other elastic element used in concrete sleepers track is the under sleeper pad (USP). They are glued underneath the sleeper. Due to the mass of the sleeper and the rails, they are quite effective in reducing the natural frequency, and as such, reducing the transfer of dynamic forces. The second effect of USP is the reduction of contact stress between sleeper and ballast particles. The contact area is increased to ~ 35% of the total calculated area (instead of 5-10% without). This not only better distributes the load, but also reduces the magnitude of forces into many smaller 'streams'. USPs are 10-20mm thick and have been used for approximately 20 years in special applications. In recent years, the use of



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Getzner, SLB3007G, with a static stiffness of 0.3 N/mm³. In France, the material is Sylomer SLB 2210G, with a static stiffness of 0.22 N/mm³. But other materials and manufacturers could well compete. Experiments with permanently deformable (plastic flow) materials could be interesting as well.

In Figure 3, the various elastic elements in a ballasted track are displayed. Publication⁹ provides a comprehensive overview of the influence of USPs on the dynamic behaviour of track.

How to apply the various elements in practice?

Of course, the best solution is a well balanced elastic design in the first place. A high elastic track is less prone to deterioration, development of rail corrugation and phenomena associated with mud-pumping. However, due to budgetary limitation often compromises are made in the design and therefore the ideal elasticity is not realised, which then often leads to a more rapid degradation of track quality and earlier renewals. In practice sometimes also local problem areas are encountered where, for instance, tamping and ballast cleaning are difficult to be performed, or totally impossible. This is for instance illustrated in the photograph in Figure 4, where due to the drainage system and the platform walls no ballast cleaner can operate. Moreover, the dense traffic (60 MGT per annum) causes the time slots for maintenance

USPs has increased, mainly in newly built high-speed railway tracks in Central Europe. Important research and tests on application of USP were published by Dr. Schilder of ÖBB⁸. The USPs normally consists of a polyurethane elastomeric material which has a foam structure. Often the USP is composed of two materials, whereby an outer material protects an inner material from abrasive wear. The materials must be well chosen in order to get good damping and stiffness values.

The pads in Austria are made from polyurethane produced by

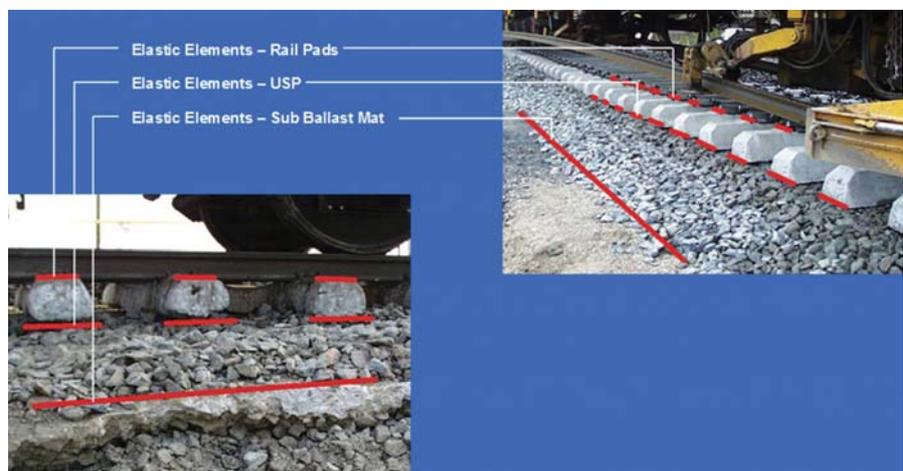


Figure 3: Overview of various elastic elements in a ballasted track

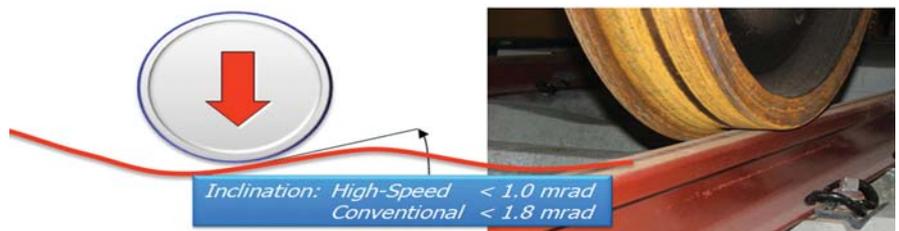


Figure 4: Location on Mumbai Suburban Railways where mechanized - ballast cleaning is impossible

to be very restricted. In those situations it pays to carry out spot repairs with USP sleepers and high elastic rail pads. In fact, the ballast elasticity is restored by these additional elements. However, it is vital to achieve a smooth rail geometry in the first place and to remove rail damage by surface welding, grinding, or partly renewal of rails, to limit dynamic excitations. In those places where mechanised tamping is not possible, it is often better not to tamp at all and leave the ballastbed untouched. The elasticity can be restored, as stated before, and the geometry could be corrected by shimming. Alternatively, a very promising and versatile method would be to place plastic bags

WELD STANDARDS BASED ON FORCE

$$F_{dyn} = Constant * v^2 * Inclination$$



underneath the sleepers and inject them in situ with an elastic material – like what is done for leveling and supporting the J-slabs and rail seats in the Japanese Shinkansen system. In

this way, both the vertical position and vertical elasticity could be controlled.

A second alternative for spot repair is the use of USP in combination with stone blowing. This also leaves the



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ballastbed untouched so that no initial settlements due to consolidation will occur. For further details on the stoneblowing principle please refer to reference points 6 and 10.

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BIOGRAPHY



Coenraad Esveld

After his graduation, Professor Esveld held various positions in the Permanent Way Department of Netherlands Railways. In 1990, he left the railways and started his consulting company Esveld Consulting Services. He was appointed Professor of Railway Engineering at TU Delft in 1993. Dr. Esveld was involved in various railway projects with, amongst others, the high-speed lines in Holland, Korea and Taiwan. He is author of the book *Modern Railway Track*.