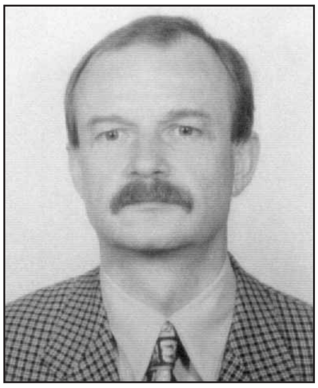
Track maintenance strategies for ballasted track – a selection



Dipl.-Ing. Dr. B. Lichtberger
Head of Research & Development
Plasser & Theurer, Linz, Austria

Maintenance strategies

The selection of the work technologies and machines to carry out track construction and maintenance should be aimed at achieving a high initial quality of the track, at lowering the track geometry deterioration rate and, thus, at extending the service life of the track.

The diagram in Fig. 1 schematically shows the track quality curve, whereby track quality deterioration is represented linearly. When the threshold for action is reached, track tamping is carried out; this leads to a decrease in the standard deviation of the track faults. This improvement is followed by a period of rapid exponential growth of the track faults, characterised by the breaking-off of points of the ballast stones [1] and their re-settlement into a more compact position. This phase of initial settlement is completed after around 0.5-2 million gross tons (MGT) of traffic borne. After this, the fault increase is linear [2]. Investigations show that the settlement (and also the standard deviation of the track faults) depends above all on the highest axle loads carried (Fig. 2) [3].

The major parameters of track quality deterioration are:

— *the initial quality:* the higher the initial quality of the track, the greater the quality reserve, and the longer it will take until the threshold for action is reached again. A high initial quality is achieved on a given track design by the use of:
   — optimum work technologies and methods;
   — high-quality track maintenance machines; and
   — high-quality track materials.

   During its entire service life, the quality of a track depends directly on the initial standard achieved at the time of its installation;

— *the initial settlement:* the rapid loss of track quality within the first MGT of traffic borne is called the initial settlement;

— *the deterioration rate:* the deterioration rate of track quality corresponds to the rise of the curve. The flatter the curve runs, the larger the maintenance intervals and the lower the costs for maintenance will be. Sato [4] showed that the frequency distribution of the deterioration rates of track quality follow an exponential distribution.

   The deterioration rate can be influenced by the following parameters [5]:
   — a greater moment of inertia of the rail slows down the deterioration;
   — a reduction in sleeper spacing has a favourable effect;
   — short curve radii have a negative effect;
   — homogeneously consolidated subsoil and ballast layers are an important factor for the durability of the track geometry;
   — fluctuations in vertical elasticity show negative effects;
   — the spectrum of forces acting on the track is a decisive factor, especially at high speeds. Dynamic forces, particularly the maximum dynamic forces that occur, cause over-proportionate damage to the track [6] and influence the deterioration rate considerably. Conversely, the combination of grinding directly after tamping can lead to a substantial reduction in the deterioration rates. This can only be explained by the reduction of dynamic forces which is achieved by grinding.

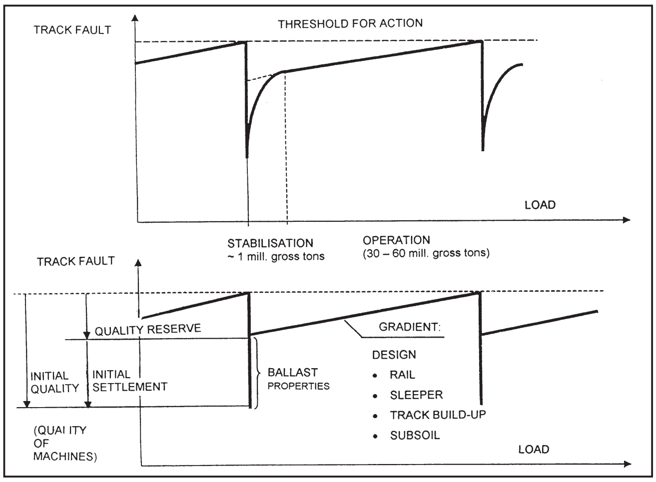


Fig. 1: Diagram showing track quality curve

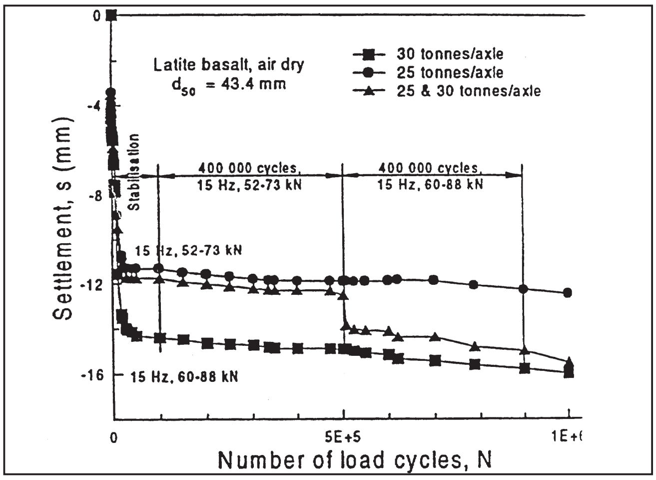


Fig. 2: Settlement resulting from a number of different load applications

The angular character of the ballast has a great influence on its settlement. Fouling of the ballast leads to clogging of the cavities in the lower layers, thus yielding to an accelerated destruction of the ballast and, consequently, to an increase in the track geometry deterioration rate. Fouling also prevents water drainage.

Dynamic track stabilisation

An investigation carried out by the Technical University of Graz yielded that a surprisingly few areas of the underside of the sleeper actually contact the ballast. In the case of wooden sleepers, the areas of contact ranged between 4 and 10%, and in that of pre-stressed concrete sleepers between 1 and 9%. Whereas in the case of newly installed track, it ranged between an astonishingly low 0.5 and 3% [7]. By tamping and then stabilising the track, the latter by means of the Dynamic Track Stabilizer (DTS), the areas of contact increase by around 40%. To increase the areas of contact and, thus, improve the load distribution behaviour, it is recommended that, besides stabilisation, the ballast stone composition (adding 15% ballast of grain size 2) and ballast shape are optimised, and an elastic coating applied to the underside of the sleepers. The larger the areas of contact, the better the load distribution behaviour and the lower the rapid initial deterioration of the track geometry will be under the initial traffic following maintenance work.

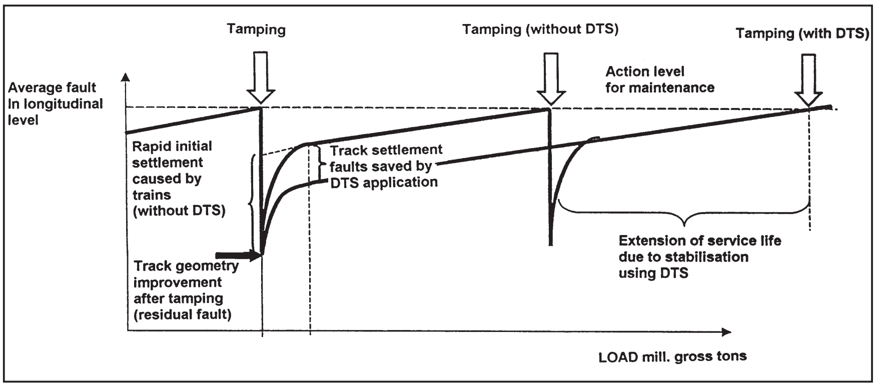


Fig. 3: Diagram showing track quality curve vs. operating load - extension of the maintenance interval achieved by dynamic track stabilisation (DTS)

From experience gained in practice, it is known that the DTS anticipates 30-50% of the initial settlements of a track following maintenance work without substantial loss of track quality [8]. Contrary to the stochastic mixture of forces which are introduced into the track by passing trains, causing uncontrolled settlements, the DTS applies a singular frequency with which it settles the track in a selective and controlled manner. Fig. 3 illustrates the impact of this work technique on maintenance intervals. As can be observed, due to stabilisation a reduction in quality loss during the first MGT of traffic borne is achieved and, thus, the quality reserve is increased.

Both theoretical investigations and experience gained in practice have yielded that the use of the DTS results in a 30% extension of the maintenance interval. Fig. 4 shows the results of a long-term trial which was carried out in the Regensburg region of German Rail (DBAG). As can be observed, the sections stabilised by the DTS show a much smaller increase in faults than those that were not stabilised. An analysis of the track irregularity densities yielded that, above all, the long-wave faults were eliminated more lastingly in the stabilised sections.

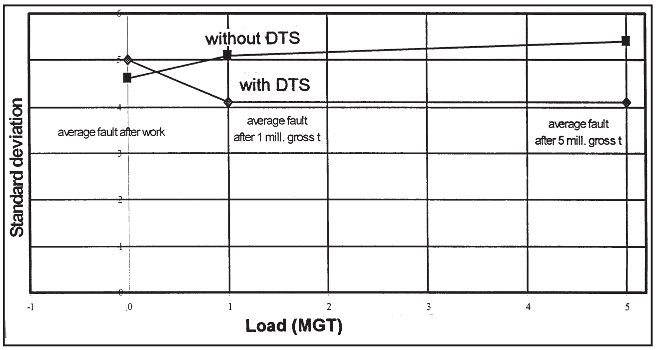


Fig. 4: Standard deviations of track alignment faults after maintenance (with/without DTS)

The effect of consolidating equipment decreases with depth. This points to the necessity of *layer-by-layer installation of ballast*, in order to produce a homogeneous build-up [9]. Thus, when a new track is being installed, and also during track renewal and ballast cleaning, ballast is inserted in layers, with each layer being tamped and stabilised individually. This ensures that smaller forces act on the lower layer of ballast, which results in a slower settlement process. As noted earlier, it is of great importance that from the very beginning the track is of the highest initial quality.

Tamping

Fig. 5 [10] shows the improvements in standard deviation of track faults achieved as a result of tamping. Tamping has a homogenising effect and, thus, has a favourable impact on the track quality deterioration rate [11].

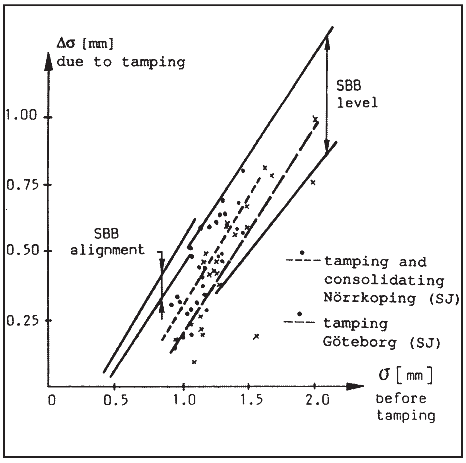


Fig. 5: Improvement of level and alignment as a result of tamping

Machine selection to handle the tasks at hand

Today, there is a wide range of track maintenance machines available, from simple designs to sophisticated machines, which enables the ideal solution to be found for each specific task. For instance, a high-speed line has different demands with respect to the quality of the track than one which carries traffic at 80 km/h. It is economical and, also necessary from a technical point of view, to use only machines that offer the latest standard of technology on main and high-speed lines.

Important differences in the machines available include:

— *the working speed:* the working speed of tamping machines, for instance, ranges from 500 to 2400 m/h. Naturally, it is of great importance that on main lines traffic disruptions are kept to a minimum; this demands that the fastest machines are used here. This criterion also applies to other machines. For instance, catenary renewal using the assembly-line method is faster by far than the conventional method whereby work is performed in sequences;

— *the work quality:* with respect to tamping, for instance, the length of the machine used has an influence on the accuracy of the regulating systems and the lining and lifting forces required. The lower these forces, the smaller the rebound forces of the corrected track will be. The design of the work units, whether one, two or three-sleeper tamping units (Fig. 6), also has an influence on the achievable quality. The more sleepers are tamped in one pass, the more uniform and durable the track geometry will be. If, for instance, three sleepers are tamped simultaneously, the machine travels forward three sleepers to the next position and in this manner fixes the good track geometry achieved with its rear axles; thus, the tendency of the track to spring back will be minimised.

Fig. 6: Three-sleeper tamping unit of the continuous three-sleeper tamping machine 09-3X Tamping Express

The call for higher work output in existing track possessions and rising quality expectations place increased demands on the track maintenance machines, i.e. requiring:
— shorter set-up and close-down times;
— high transfer speeds;
— high working speeds; and
— a high availability.

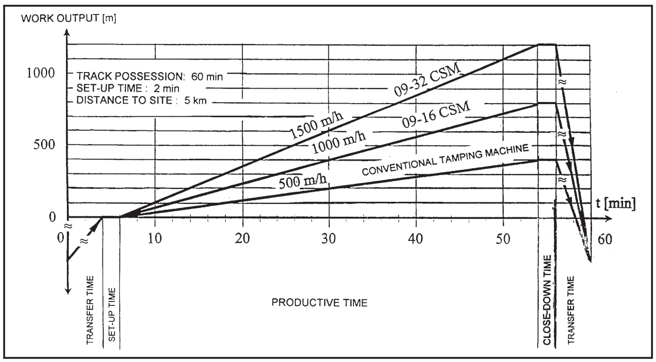


Fig. 7: Output of track maintenance machines dependent upon transfer time, set-up and close-down times and working speed

Fig. 7 shows the correlation between transfer time, set-up/close-down times and productive time [12]. If the effect of a 10% improvement of the individual influencing parameters on the length of the productive time is calculated, the following results are obtained:
— longer track possessions show the greatest effect on productivity;
— the average working speed of the machine is the second largest factor;
— a shortening of the set-up times, or a rise in transfer speeds (currently ranging between 90 and 100 km/h, with a tendency towards 120 km/h), only achieves a small increase.

Therefore, machine manufacturers concentrate their efforts on the further development of the working speed. In this respect, a significant jump in productivity has been achieved with the introduction of the three-sleeper tamping machine (2200 m/h), as compared to that of the two-sleeper tamping machine (1500 m/h), i.e. an increase in output of 40%.

Mechanised spot fault elimination

Individual trouble spots in the track or on switches, bridges and level crossings, as well as spot faults which have arisen due to other factors (subsoil problems, mud spots, loose rail fastenings, damaged joints, etc.) are very frequently the characteristics of a poor track geometry. Spot faults should be removed as soon as possible, i.e. *before they induce a cost-intensive speed restriction zone and operational hindrances*. A timely elimination limits an extension of the faults. However, 'normal' maintenance measures, using the method of manual repair currently practised on most railways, bring unsatisfactory results, are time-consuming, and are labour and cost-intensive, and only achieve short-term improvements.

The application of a specialised spot fault elimination machine, such as the UNIMAT Sprinter (Fig. 8), can help to achieve a long-lasting improvement Mechanised spot fault elimination leads to a 75% reduction in maintenance costs and to a reduction in maintenance time by a factor of 5 [13].

Modern quality control methods

Newly developed laser distance measuring systems are available which help to achieve a high quality of the track geometry when using track renewal trains or ballast cleaning machines (e.g. RM 800), in that they enable the track to be installed accurately to the centimetre in relation to the adjacent track. This simplifies the control work, and increases both the output and quality of work, thus making the use of tape measures or graduated rods or pegs, used until now to measure track spacing, obsolete.

Fig. 8: UNIMAT Sprinter spot fault elimination machine

Further, computer guiding systems exist which automatically guide the track maintenance machines in accordance with the target track geometry.

Accurate to the millimetre correction value measurement for track geometry correction

The quality of the track geometry that can be achieved by a tamping machine is only as good as the defined correction values. It is therefore of great importance that the most accurate calculation of the correction values is made.

With the EM-SAT 120 electronic track survey car, a machine is now available which can record long-wave longitudinal level and alignment faults up to a wavelength of 250 m, accurate to the millimetre. The EM-SAT 120 uses a laser chord, placed between the main machine and a self-propelled satellite, as a measuring reference (Fig. 9). The measurement of longitudinal level and alignment is performed simultaneously at an average working speed of 2.5 km/h.

Fig. 9: EM-SAT 120 track survey car

At present, six EM-SAT 120 track survey cars are working on DBAG, and three on Austrian Federal Railways (ÖBB). On each of these railways one machine is equipped as a prototype with a GPS measuring unit. This innovation enables the capture of highly accurate laser reference chord data in absolute track co-ordinates. In the future, large savings are expected due to the possible abolition of measuring fixed points, and maintenance of the latter [11].

Compared to the manual-optical method of correction value measurement (sighting with versine off-set device and surveying, or similar), the automated method using the EM-SAT 120 is five times more efficient than conventional methods and, thus, very cost-effective.

Cost-effective track formation rehabilitation

In Austria, a machine system has been developed (AHM 800-R track formation rehabilitation machine) which, in the course of formation rehabilitation, removes the top layer of usable ballast, crushes it and then, adding new material, inserts it as a formation protective layer which it, finally, also consolidates (Fig. 10).

Besides the costs for disposal, the use of the AHM 800-R also saves on the costs for the appropriate quantity of new material, the costs for transport of the saved new formation protective layer material and that of the used ballast.

Fig. 10: AHM 800-R formation rehabilitation machine

Together with DBAG and the German contracting firm Wiebe, a system has been developed (the RPM 2002, a formation rehabilitation machine with integrated recycling of ballast) which can excavate, clean and break ballast stones for re-use in the track. Lacking ballast is replaced from the supply of new ballast on the machine. The system saves ballast and reduces the portion of disposal costs that would otherwise be incurred for the excavated material. Moreover, there are no transport costs for the re-cycled ballast.

Economic evaluation of track maintenance technologies

Models exist which can be used to describe and study the development of track faults and to calculate the most economical form of track maintenance technology to be applied. For instance, the model described in [15] is specialised in making economic comparisons of various track maintenance technologies.

Contrary to the purely statistical calculation of the overall costs by life-cycle-cost (LCC) models, this model uses a dynamic cost-efficiency calculation, i.e. it assumes that the costs and prices are variable throughout the service life of the track. The advantages of the LCC method, enabling calculations early on in the project development stage, have been integrated.

Various norm kilometres (which are typical for the line network) are defined in the model. All costs such as labour costs, material costs and machine costs must be entered. These are complemented with freely selectable growth rates.

As an example, here follows a summary of strategies that were attained for ÖBB, by using this model [16]:

- speed restriction zones on the main network are extremely uneconomical and, thus, to be removed immediately;
- an increase in axle load to 25 t leads to a 20% rise in costs on high density lines;
- in curves featuring short radii, it is far more economical to use concrete sleepers, despite strong rail corrugation formation requiring frequent grinding, than wooden sleepers featuring safety caps;
- the rehabilitation of poor subsoil conditions on main lines is highly economical, as compared to a strategy of high maintenance intensity without rehabilitation;
- the combination of grinding directly after tamping is highly cost-effective; savings of 10,000.- DM/km can be expected.

Conclusions

The initial quality and the deterioration rate of the track geometry following maintenance work are the most important quality indicators of a track. In view of achieving the highest possible cost-efficiency, the work technologies and machines selected should contribute to decreasing track geometry deterioration rates and ensure a high initial quality of the track.

References

[1] Leykauf G., Mattner L.: ‘Elastisches Verformungsverhalten des Eisenbahnoberbaus’, Der Eisenbahningenieur, No. 3/1990.

[2] Lichtberger B.: ‘Die dynamische Gleisstabilisation und die optimale Instandhaltungstechnologie’, VDEI Eisenbahningenieurkalender 1998.

[3] Ionescu D., Indraratna B., Christie H.D.: ‘Deformation of railway ballast under dynamic loads’, Conference on Railway Engineering, Rockhamprton, Queensland, Australia, 7-9 September 1998.

[4] Sato Y.: ‘Optimum track structure considering track deterioration in ballasted track’, Proceedings Sixth International Heavy Haul Railway Conference, Cape Town, South Africa, 6-10 April 1997.

[5] ORE D117 Report No. 2: ‘Optimale Anpassung des klassischen Oberbaus an den künftigen Verkehr’, Utrecht, April 1973.

[6] Eisenmann J.: ‘Die Weiterentwicklung des Eisenbahn-Oberbaus - Auswirkung auf Langzeitverhalten und Körperschall-Emission’, ZEV+DET Glasers Annalen. No. 4/1996.

[7] Jani J.: ‘Experimentelle Ermittlung der Kraftübertragungsflächen zwischen Beton-/Holzschwellen und Oberbauschotter’, Thesis, Institute for Railway Systems, TU Graz, Austria, May 1993.

[8] Lichtberger B.: ‘The homogenisation and stabilisation of the ballast bed’, Rail Engineering International, Edition 1993, Number 1.

[9] Lichtberger B.: ‘Die Gleisqualität: Die Grundlage für effizienten Eisenbahnbetrieb’, VDEI Eisenbahningenieurkalender 1994.

[10] Esveld C., Jourdain A., Kaess G., Shenton M.J.: ‘Historic data on track geometry in relation to maintenance’, Rail Engineering International, Edition 1988, Number 2.

[11] ORE D161 Report No. 2: ‘Dynamische Erscheinungen der Wechselwirkung Fahrzeug/Gleis aus der Sicht der Gleisunterhaltung’, Utrecht, April 1987.

[12] Dannenberg H., Lichtberger B.: ‘Erhöhung der betrieblichen Verfügbarkeit der Gleise durch rechnergestützte Planungsmethoden und die Nutzung von Hochleistungsmaschinen’, VDEI Eisenbahningenieurkalender 1992.

[13] Pech F., Lichtberger B.: ‘Automatische Einzelfehlerbehebung’, ETR-Eisenbahntechnische Rundschau, No. 12/2000.

[14] Marx L., Lichtberger, B.: ‘Elektronisch gestützte Messarbeiten in Gleisen und Weichen mit GPS-Anbindung’, Der Eisenbahningenieur, No. 6/2000.

[15] Veit P.: ‘Rechenmodell zur wirtschaftlichen Bewertung von Gleisbautechnologie’, ÖVG-Spezial, Editon 41, September 1997.

[16] Veit P.: ‘Wirtschaftliche Bewertung von Strategien im Bereich Fahrweg’, ETR- Eisenbahntechnische Rundschau No. 5/2000.

This article has been reproduced on this CD-ROM from Rail Engineering International with kind permission from
©De Rooi Publications, The Netherlands, Fax: +31 318 511243