RTR

n° 1/2004, pp. 28-32, bibliogr., fig. - *(REVUE) - S/C : 0610*

Evaluation des schémas de réparation de voies sans ballast de diverses conceptions.

HS

Appraisal of repair concepts for different designs of ballastless track

The occasional accidents that occur on the railway as a system may have their causes in human error or in technical failures. However, since even small disruptions on the permanent way can affect the whole network, given the linearity of its component parts, it is worth giving considerable thought to the question of how much time is required for mending any damage done to the permanent way, for instance, as a result of a derailment.

Ballasted track is a system that has served the railways well, but it does require a relatively high outlay on maintenance. This has led both academic and industrial researchers to develop novel types of track, where concrete or asphalt comes in to replace ballast. The initial capital outlay on such ballastless track (alternatively called "slab track") is higher, but it may still be the more profitable business option for heavily-trafficked lines on account of the reduced maintenance outlay and the improved track stability.

The author presents repair concepts for some of the types of ballastless track in use on the networks of Deutsche Bahn (DB Netz), Railned (Netherlands) and the Austrian Federal Railways (ÖBB) and goes on to make a systematic comparison between them.

1 The various types of ballastless track

Once the new high-speed line between Nuremberg and Ingolstadt has been completed, about 1.3 % of the total track kilometres operated by Deutsche Bahn (DB Netz, to be more precise) will be in ballastless track. More than 17 different types of such track have been used in Germany to date, and Germany has the world's second-largest experience with the technology; only Japan has more.

To simplify matters, the various types can be grouped into three main categories: monolithic, directly-supported and special systems. Nearly all the ballastless track used by Deutsche Bahn to date is of the monolithic sort, and the various sub-types belonging to the Rheda model account for the lion's share of this. One particular subgroup within the monolithic types is that formed by designs that are based on track slabs (Bögl and ÖBB-Porr).

One essential difference between the directly-supported types and the monolithic and special types is the possibility of replacing individual supports in a manner similar to ballasted track. This also applies to the rubber-supported sleepers used for points on the Austrian Federal Railways (ÖBB) [12].

Six slab-track types were selected as examples for a comparison of the repair of the damage caused by a train derailment, taking different damage scenarios:

- ▷ Prefabricated Bögl slab,
- ▷ Prefabricated ÖBB-PORR slab,
- ▷ Infundo,
- ▷ FFYS,
- ▷ Rheda 2000,
- ▷ Getrac A3.

Table 1: A typology of ballastless track *(Source of all tables and figures: the author)*

Category	Characteristics	Type – Examples
Monolithic systems	Material fit between the support and the concrete support layer	Heitkamp, Rheda, Züblin
	Systems with track slabs	Bögl, ÖBB–PORR, IPA system (Italy), Type VA (Japan)
Directly supported systems	Firm/form fit between the support and the concrete or asphalt support layer	ATD, Biblock, BTD, FFYS, GETRAC, Walter
Special system types	Special-purpose designs that have to date only been used in locations with particular constraints	Mass-and-spring systems, fully embedded rails (e.g. Infundo)

Dipl.-Ing. Peter Danzer

TU Berlin, FG Schienenfahrwege und Bahnbetrieb Sekr. SG 18. –
Anschrift: Salzufer 17-19, D-10587 Berlin.
E-Mail: PDanzer@railways.tu-berlin.de

2 Catalogue of requirements for the construction of ballastless track

Ever since Deutsche Bahn issued its first catalogue of requirements for the construction of ballastless track back in 1994, it has been a mandatory requirement for a repair concept to be submitted in the course of the approval process. Back then, one of the demands was that it had to be possible to replace 1000 m of track in six days at most [2.1]. A complete replacement of the track within six days combined with a concrete setting time of 28 days before full loading through traffic is permitted is, to say the least, a tall order, even if the concrete used is of a higher strength class than stipulated in the specifications. The six-day time constraint for "renewal" is thus primarily only applicable to repairs to the existing track.

When the third version of the catalogue of requirements was published in 1995, it included the provision that any contractors submitting tenders had to incorporate a repair concept in them, including performance data, for making good the consequences of accidents [2.2]. The requirements no longer contain actual figures based on time and/or lengths of track. It was after the third catalogue of requirements came into force that the new high-speed Cologne—Rhine/Main line was built.

The fourth revised version of the catalogue also contains no specific figures for time requirements and/or lengths of damaged track to be repaired. Contractors are requited to draw up detailed repair and damage concepts for the following two damage scenarios and to submit them to Deutsche Bahn [2,3].

- ▷ damage affecting the top surface of the ballastless track, namely the sleepers, the rail fastenings and the rail supports; and
- ▷ deeper damage, affecting the support layer too.

3 Accident risk

There is no such thing as a technical system that does not harbour some form of residual risk, such as that of a trail derailing on a railway. Every derailment leads to some deterioration in the functional properties (such as to timber sleepers) and may even cause lasting damage to permanent-way components.

Taking the network operated by the former Deutsche Bundesbahn between 1949 and 1993, the incidence of accidents decreased despite an increase in the total number of train-kilometres, although the number of derailments per million train-kilometres remained more or less constant as of the mid-1970s [8].

Taking the five-year period, 1989-1993, the then Deutsche Bundesbahn had 108 freight-train derailments on open track, corresponding to an annual mean of just under 22. Taking those derailments where the cost of the damage to the vehicle was greater than around 1500 euros, 28 occurred at speeds between 36 and 80 km/h and 14 at speeds in excess of 80 km/h. Putting the two categories together, the annual mean was around 8.4 [8]. Between 1997 and 2002 approximately 9.7 derailments occurred annually on open track [4].

With a total of 225 million freight-train kilometres (figure for 2000), it is to be reckoned that for each million freight-train-kilometres, there will be between 0.0431 derailments (for an annual total of 9.7 derailments) and 0.0373 (for an annual total of 8.4 derailments). On a 100-km section of track carrying 10 000 freight trains per year, there will thus be one derailment on average roughly every 23-27 years.

4 Quantification of accident severity

The author is not aware of any assessments that would make it possible to predict the extent of damage to the track caused by a wagon derailing. The most important influences are the type of track, the train speed, the axle load, the type of vehicle and the position of the derailed wheelset within the train.

At present, it is not possible to quantify the amount of damage caused to the track as a consequence of an accident, because we simply do not know enough about the limiting conditions. The Railway Institute at the Technical University of Berlin evaluated derailment experiments with a freight wagon [6]. A tank wagon was running at the back of a train at speeds between 13 and 43 km/h, and a derailment was induced in its trailing bogie, first of all unladen and then with a full load. As was to be expected, the fully-laden wagon caused more damage to the track than the empty one. The tensile force acting on the wagon tends to pull it into a central position and the derailed wheel is thus dragged along right next to the rail, more or less over the rail fastenings.

The derailment of a wagon somewhere in the middle of a train occurs more frequently than one at the back of a train. A derailed wagon in the middle of a train seems more likely to jack-knife if the brakes are applied hard or if it runs over points. It is not possible to extrapolate these effects with any certainty from the range of speeds studied to higher ones. For the empty wagon with a wheel load of around 5 tonnes, it appears that speeds of greater than 37 km/h reduce the force of acceleration (risk of derailment), which could be explained by the fact that the wagon is dragged over the sleepers.

Initial simulations suggest that the wheel would penetrate the top surface of the concrete support layer, wrecking it. Once the maximum depth of damage has been reached, the wheel will roll on or in the concrete support layer [9]. The most important parameters affecting the duration of remedial work are the actual appearance of the damage, the length of the damaged track, its accessibility (embankment, tunnel, bridge, etc.) and the availability of stocks of the materials required.

The concept for mending derailment damage to Bögl-type prefabricated slab track assumes that, for a minor incident, the rail-fastening systems will be destroyed and that, for a major incident, it will be necessary to replace the whole of the support slab [1].

Taking this pragmatic approach a little further, the comparison presented later on in this article is based on the assumption that, on a double-track line, one track suffers minor or severe damage as the consequence of the derailment of one or more wagons. For the sake of simplification, the length of minor damage is taken to be 4 km and the length of severe damage 2 km. In both cases, the adjacent tracks are not affected.

5 Experience to date

In 1999, two derailments occurred on the high-speed line between Würzburg and Hanover. In March, a four-wheeled Italian freight wagon derailed in a tunnel near Göttingen as a result of a damaged bearing and then caught fire. The ballasted track's sleepers were wrecked over a length of nearly 6 km. It took more than two weeks to repair the damage. In April of the same year, four of the sixteen wagons of an "intercity goods train" ("ICG") derailed between Kassel and Fulda. The damage extended over 2.5 km of ballasted track. To repair it, the adjacent track needed to be closed for three days and the damaged track itself for five days.

In 1978, a wagon derailed in the Boetzberg Tunnel in Switzerland on STEDEF-type ballastless track [7]. In 1979, another derailment occurred on STEDEF ballastless track, this time in France, near Neuilly-Sur-Marne [3]. In both cases, the maximum train speed was 90 km/h and in both instances the supports were so badly damaged that it was necessary to replace the sleepers. No damage was done to the underlying slabs. No apparent damage was done to the rail fastenings, and in both cases the damage was mended in a matter of days, since it was only the sleepers that had to be replaced.

In 2000, a wagon derailed near Melk in Austria on the route between Linz and St.-Pölten as a consequence of an axle fracture. Severe damage was caused to all supports over a length of 4.5 km of ÖBB-PORR ballastless track and over the following 400 m section of ballasted track. The situation was rendered more difficult in that the section of damaged ballastless track extended through two tunnels, the open track between them (about 1 km) and over a bridge (150 m). It would have been possible to continue to use the track with a speed restriction of 60 km/h even before repairing the damage. It was limited to a twisting of the sleeper screws and the tensioning clamps in the direction in which the derailed wagon had been moving, together with tears in the angular guide plates and incisions in the pressure distribution plates [13].

It took about 28 working days to repair the damage. New supports made of UV-resistant polymer concrete were inserted between the old damaged ones. It was decided not to work out penalty charges, since the incident occurred on a four-track section. The following aspects are particularly noteworthy:

- ▷ The noise-absorbing elements laid in the tunnels acted like guard rails;
- ▷ On a per-unit-length basis, the costs for repairing the ballastless track were lower than for the ballasted track;
- ▷ Given that the supports were relatively soft, the axle stubs more or less slid over the rail fastenings, which reduced the extent of impact damage. The height-adjustment plates have a stiffness of 19.6 kN/mm and are thus softer than those used by Deutsche Bahn for its ballastless track with a stiffness of 22.5 ± 2.5 kN/mm.

6 Repair concepts for selected slab-track types

This section outlines repair concepts for six types of ballastless track: prefabricated Bögl, ÖBB-Porr, Rheda 2000, FFYS, Getrac A3 and Infundo. The data is taken from the literature, with additions from the author.

6.1 Monolithic system: Bögl prefabricated slab

Minor derailment damage
New supports (such as DFF 300) are inserted in between the damaged rail fastenings. New dowel holes are drilled into the base to hold these. This solution has the advantage of maintaining all the usual means for correcting any fault in the height or position of the track. If the supports are only slightly damaged, any parts knocked loose can be replaced with UV-resistant polymer concrete.

Severe derailment damage
For straight sections of track, it is assumed that a sufficient number of track slabs will be held in stock (308 slabs are required for a 2-km-long section of track). Once the scene of the accident has been cleared, auxiliary rails are laid next to the track slabs. The connections between the slabs are severed, and a horizontal band saw is used to separate the slabs from the bituminous emulsion. A gantry crane carries them away.

The bituminous emulsion is then ground away and the support layer is cleaned up. The gantry crane then lowers new track slabs onto the support layer, positioning them with precision. The rails are tightened, one standard length at a time, and the track slabs are aligned and then backfilled.

If the damaged section of track is accessible for work from both sides, it is possible to clear the damaged track from one side, whilst laying new track slabs from the other side. The repaired track can be reopened to traffic only a few hours after backfilling has been completed.

6.2 Monolithic system: the ÖBB-PORR system of load-bearing track slabs

Minor derailment damage
It is to be expected that with the use of softer pads, less severe damage will be caused than with supports with conventionally stiff pads. The method for repairing minor damage is similar to that for Bögl track, so is the amount of time required.

Severe derailment damage
Severe damage to ÖBB-PORR ballastless track is also dealt with in a similar way to Bögl track. The assumption is that a little more time will be required to remove damaged slabs, since at least the concrete humps, of which there are two on each slab, will need to be partly removed.

6.3 Monolithic system: Rheda 2000

Minor derailment damage
In the case of minor damage caused by a derailment, it is to be expected that the supports will suffer slight-to-severe damage. New supports are anchored into place between the old ones (for instance with Ioarv 336 or DFF 300). New dowel holes are drilled into the base. The amount of time is similar to slab track of the Bögl and ÖBB-PORR types.

Severe derailment damage
It is necessary to replace the entire track slab. The rails are taken out and moved over to the sides, where they can be fixed to be used by a crane. The slab is cut into small sections and separated from the hydraulically bonded layer (HBL) beneath it by being pushed horizontally. Once the debris has been cleared, a new concrete slab is put in place on the HBL. The requisite concrete strength is achieved after 28 days.

6.4 Directly-supported System: FFYS

Minor derailment damage
The Y-shaped steel tiebars are slightly damaged as a result of the derailment. On heavily trafficked track, the practice is not to repair the steel sections by simply straightening them, but rather to replace entire tiebars. The assumption is that the derailed wheel is dragged over the tiebars in such a way that its flange does not dig into the asphalt support layer. In the version of this track that uses concrete

Table 2: Appraisal criteria and scores

Score	Time requirements	Outlay on keeping spare parts	Lateral access / Second track
1	up to 1 week	modest	not necessary
2	1 to 3 weeks	stock of universal special components (sleepers) for all track geometries	beneficial (second track)
3	more than 3 weeks	stock of different special components (track slabs) for each possible track geometry	essential (second track)

and not asphalt, this material is not damaged either.

Auxiliary crane rails are laid next to the track. The track panel section is pressed out of its grooved anchorage with winches (for the asphalt version without Nelson anchors). Alternatively, the anchor bolts of the version with a concrete support layer are loosened. The track is cut up into panel sections and carried away by a gantry crane. The top asphalt layer needs to be ground away and replaced with a new one in order to compensate for and cavities that may have arisen during operations and/or indentations due to the sleepers caused by the derailment.

Severe derailment damage
The steel tiebars are so severely damaged that they have to be replaced. Given that the sleepers have a height of only 95 mm, it must be assumed that the wheel flange will damage the top surface of the asphalt support layer too. This is ground away and replaced with new material. All the other repair measures are identical to those for "minor derailment damage" discussed above.

6.5 Directly-supported system: Getrac A3

Minor derailment damage
As with the FFYS type of ballastless track, the assumption for Getrac A3 too is that the derailed wheel will be dragged over the sleepers more or less where the supports are. Despite that, there is a risk that the wheel will hit into the sleepers, making it necessary to replace them. The asphalt support layer will, however, not be destroyed by this. For carrying out repairs, auxiliary crane rails are positioned next to the track. The track is cut into panel sections and carried away by the gantry crane. The top asphalt layer needs to be ground away and replaced with a new one in order to compensate for any cavities that may have arisen during operations and/or indentations due to the sleepers caused by the derailment.

Severe derailment damage
The difference here compared with minor derailment damage is the assumption that the derailed wheel will not simply be dragged over the sleepers but will hit each one of them hard. All the sleepers suffer appreciable damage and need replacing. The repair measures are identical to those for minor derailment damage.

6.6 Special type of system: Infundo (continuously supported, fully embedded rails)

If a derailment occurs, the flange that is on the inside of the track will cut into the concrete and keep running parallel to the rail. It is also feasible that the outer flange could cut into the Corkelast layer, whereby the concrete edge might have the effect of guiding it. In the absence of any deliberate form of guidance (which is the case for the other track types described above too), there is nothing to guarantee that the wheels of the derailed wagon will stay next to the rails.

Minor derailment damage
In the case of minor derailment damage, the wheel flanges will cut grooves into the concrete slab on one side of it and also between the rails. That is not likely to increase the risk of further derailment, so the damage can simply be repaired during scheduled pauses between trains.

Severe derailment damage
If severe damage is caused by a derailment, is will be necessary to replace the track slab. The old slab is cut into short sections, as for the monolithic Rheda system and carried away by a gantry crane. To shorten the time needed for the whole operation, prefabricated slabs of a type known as Bögl-Infundo are laid instead of building up an original Infundo track.

7 Appraisal of the various track designs

Having briefly sketched out the various repair concepts, the time has now come to compare them in terms of the time required until normal running becomes possible again on the repaired/replaced track, the need for lateral access (for instance from a second track) and the outlay on maintaining a stock of spare parts. One of the conditions applied for the appraisal is that the second track must remain available for train services, even if at a reduced speed. The considerations presented below are based on the following criteria and weightings:

▷ time required: 60 %,
▷ outlay on keeping spare parts: 30 %,
▷ lateral access / usability of second track: 10 %.

Each track type is awarded points for each of these criteria, with a worst score of three and a best score of one (Table 2).

The time necessary for returning the track to unrestricted normal operation has the highest weighting with 60 %. This criterion depends on numerous factors, not least the availability of labour (number of shifts per day), machines and the necessary materials, such as sleepers and track slabs. Another key time factor is the outdoor temperature, although appropriate construction techniques can reduce its impact.

The costs are only considered indirectly through the criteria of time requirements (= penalty charges) and the outlay on maintaining spare parts. The appraisal was carried out for three different scenarios:

▷ minor derailment damage over 4 km of track,
▷ severe derailment damage over 2 km of track, single-shift repair work,
▷ severe derailment damage over 2 km of track, two-shift repair work.

The lower the total score, the better a type of track is considered to perform.

The results of the appraisal are shown in Tables 3-5. One evident conclusion is that the rectification of derailment damage is achieved fastest with prefabricated slabs and with the asphalt-based technologies. Where it is possible to work faster (two shifts instead of just one), the advantages of the repair techniques using prefabricated track slabs are even more pronounced. These results do not vary

Type of ballastless track	Time requirements (60%)	Stocks of spare parts (30%)	Need for lateral access (10%)	Result
Bögl	2	3	1	2.2
PORR	2	3	1	2.2
Rheda	3	3	3	3.0
FFYS	2	2	1	1.9
Getrac A3	2	2	1	1.9
Infundo-Bögl	2	3	1	2.2

Table 3: Appraisal of minor derailment damage of 4 km of track, single-shift repair work

Type of ballastless track	Time requirements (60%)	Stocks of spare parts (30%)	Need for lateral access (10%)	Result
Bögl	1	1	1	1.0
PORR	1	1	1	1.0
Rheda	1	1	1	1.0
FFYS	2	2	1	1.9
Getrac A3	2	2	1	1.9
Infundo-Bögl	1	1	1	1.0

Table 4: Appraisal of severe derailment damage of 2 km of track, single-shift repair work

Type of ballastless track	Time requirements (60%)	Stocks of spare parts (30%)	Need for lateral access (10%)	Result
Bögl	1	3	1	1.6
PORR	1	3	1	1.6
Rheda	3	3	3	3.0
FFYS	2	2	1	1.9
Getrac A3	2	2	1	1.9
Infundo-Bögl	1	3	1	1.6

Table 5: Appraisal of severe derailment damage of 2 km of track, two-shift repair work

significantly even if the weighting factors are modified.

Given the large number of monolithic track types, plus one special design, and their various overall heights, different prefabricated slabs need to be kept in stock for each overall height (Fig. 1). Supported types (whether asphalt or concrete) can be repaired faster in situ than monolithic types.

By using a higher grade of concrete (strength class B 55 instead of B 35), it is possible to achieve a setting time shorter than 28 days, which is one way of accelerating repairs to monolithic types. The same consideration applies to the manufacture of track slabs. Interim solutions are fundamentally possible for all track types, the only constraint being the availability of spare parts with a similar overall height.

8 Conclusions

The probability of derailments is declining all the time, thanks to advances in the technology used for rail vehicles and sensor systems as well as the high quality of modern track. There is no precise means of forecasting the consequences of a derailment without resorting to simulations and/or practical experiments. It is a field in which further research is still needed both into further reductions in the risk of derailments and into the consequences of accidents.

As a general rule, minor damage can be rectified without needing to lay completely new track, and given the peak loads likely to be exerted on the supports, the monolithic types turn out to be more favourable in this instance. For severe damage, the best repair performance is obtained for the monolithic types with track slabs as well as the supported types, especially on account of the relatively short time needed to mend the damage.

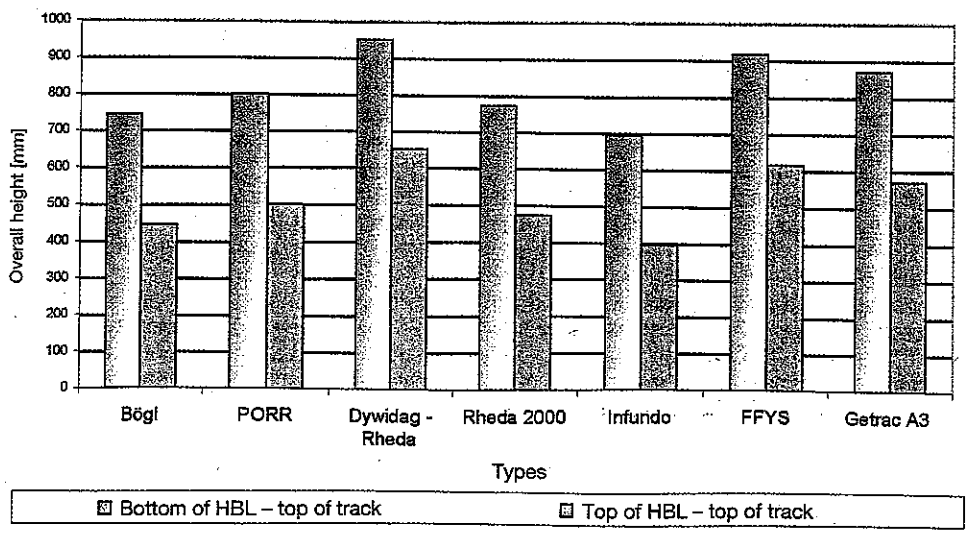

Fig 1: Overall heights of the various types of ballastless track

References

[1] Prospekt der Firma Max Bögl, Korrekturkonzept.
[2.1] DB AG Anforderungskatalog zum Bau der Festen Fahrbahn, 1. Auflage.
[2.2] DB AG Anforderungskatalog zum Bau der Festen Fahrbahn, 3. Auflage.
[2.3] DB AG Anforderungskatalog zum Bau der Festen Fahrbahn, 4. Auflage.
[3] Cervi, G.: "Remise en état de la voie sur dalle de Neuilly-Sur-Marne après un déraillement", Revue Générale Des Chemins de Fer 1980, Vol. 10.
[4] Eisenbahnbandesamt (EBA), January 2003.
[5] Fördergesellschaft Y-Stahlschwellenoberbau e.V. (FYS), Anwenderhandbuch für Y-Stahlschwellen, Frechen 2000.
[6] Hecht, M.; Jackatt, H.; Rühl, S.; Schirmer, A.; Schmidt, M.: Informationssysteme für Schienenfahrzeuge auf Bus- bzw. Telematikbasis - Phase 1: Entgleisungsversuche, TU Berlin, Fachgebiet Schienenfahrzeuge and KTT, June 2000.
[7] Hofmann, Ch. and Pfarrer, H.: Renouvellement de voie sur le troncon d'essai sans ballast dans le tunnel du Boetzberg des Chemins de Fer Fédéraux Suisses à la suite d'un déraillement, Revue Générale Des Chemins de Fer, 1980, Vol. 10.
[8] Hörstel, J.: Simulationsverfahren für Risikoabschätzungen im Eisenbahn-Mischbetrieb, Wissenschaftliche Arbeiten Nr. 46, IVE, Hanover, 1996.
[9] Könke, C.; Könke, D.; Le, R.; Ripke, B.: Simulation der Schädigungsentwicklung von Betontragplatten der Festen Fahrbahn bei einer Zugentgleisung, Symposium Feste Fahrbahn 2002, Berlin 12.-13.Mai 2002.
[10] Leonhard Weiss GmbH & Co., Infundo Feste Fahrbahn - Informationsordner.
[11] Leykauf, G.: Oberbauinstandhaltung bei einer Festen Fahrbahn, Eisenbahntechnische Randschau ETR — Eisenbahntechnische Rundschau 1999, Vol. 3.
[12] ÖBB, HL-AG, BEG: Dienstbehelf für den Bau der Festen Fahrbahn, Hochleistungsstrecken, March 2002.
[13] Dr. Schilder, ÖBB, April 2002.