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Železniške naprave - Aerodinamika - 7. del: Osnove preskusnih postopkov za zaščito pred letečim drobirjem, ki ga sproža vlak

Railway applications - Aerodynamics - Part 7: Fundamentals for test procedures for train-induced ballast projection

Bahnanwendungen - Aerodynamik - Grundlagen für Prüfverfahren für zuginduzierten Schotterflug

Applications ferroviaires - Aérodynamique - Principes généraux pour des procédures d'essais vis-à-vis des projection de ballast causés par la circulation des trains

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Contents

European foreword

This document (FprCEN/TR 14067-7:2020) has been prepared by Technical Committee CEN/TC 256 “Railway Applications”, the secretariat of which is held by DIN.

This document is currently submitted to the Vote on TR.

1 Scope

This document discusses:

- economic aspects of ballast projection;
- comparison of methods in France and Spain for rolling stock;
- infrastructure assessment methods;
- review of available literature;
- next steps and recommendations regarding standardization and research.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 14067-4 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at https://www.iso.org/obp
- IEC Electropedia: available at http://www.electropedia.org/

4 Symbols and abbreviations

For the purposes of this document, the symbols and abbreviations given in EN 14067-4 apply.

5 General aspects of ballast projection and state of the art

5.1 Introduction

The phenomenon of ballast projection caused by trains has been caused in the past by lumps of ice or accreted snow falling from the train structure during extreme winter conditions, which then strike the ballast bed causing ballast to be ejected upwards, impacting the train underside or passing trains and leading to damage. Typically, this damage includes breakage of train underbody equipment, failures of train systems or reduced efficiencies, breakages of station or train windows, and impact damage to train or trackside structures. This type of ballast projection occurs to regional trains as well as to high speed trains and has been well-known for a long period in railways world-wide.

However, in the early 2000s there were a number of significant incidents of ballast projection involving high speed trains which were not caused by ice fall, but seemed to arise from aerodynamic causes. Substantial damage was caused to the underside of an ICE3 train in one particular incident in Belgium in 2003. This phenomenon seems to be solely a high speed train phenomenon. The relevant contributory factors involve:

- the aerodynamic design of the train, particularly the train underbody;
- the air speeds generated under the train, due to the Couette-type flow created by the high speed train passing over the static track bed;
- train-induced pressures acting on the ballast;

— track vibrations caused by the traction engines and wheel passing over the rails.

The types of damage from this sort of incident principally includes: ballast stone impacts to the underbody structure and damage to the underbody equipment, pipes and cables of high speed trains, and damage to wheels and rails when ballast stones are trapped between them. Although possible, there seems to be little evidence of collateral damage to other trains or of injury to trackside workers.

It should be noted that although the aerodynamically-induced ballast projection incidents have resulted in some spectacular damage to trains, there is evidence of minor impact damage to train underbodies at lower train speeds that appears to be deemed tolerable by train maintainers. Furthermore, since the first upsurge in these incidents, there has been a complete cessation with no further incidents since 2004. This reduction in incidents coincides with measures introduced by many European Infrastructure Managers to reduce ballast levels relative to the top of sleepers.

Nevertheless, there is a widespread concern that this is still a valid train/infrastructure issue needing certain controls, which is supported by its inclusion in the LOC&PAS and INF TSIs as an issue, (albeit currently as an open point). Consequently, various national rules regarding the issue have been developed, mainly focused on rolling stock, leading to a burden on train manufacturers trying to introduce trains into different countries, as they are required to apply different methods to confirm their trains' performance with regard to ballast projection.

Within the revision published in June 2019, ballast projection is addressed in TSI LOC PAS and TSI INS as an interface issue relevant for operation with train speeds >250 km/h. The issue is connected to the essential requirements of safety and technical compatibility.

5.2 Summary of studies and incidents (by countries, manufacturers)

5.2.1 General

Table 1, reproduced from Claus [1], summarizes some of the major incidents up to 2006 of both types of ballast projection this century (those due to winter weather are not exhaustive).

Table 1— Reported past ballast projection incidents

Date	Train Type	Location	Speed	Track Type	Weather Conditions	Remarks
2001	ICE 3	Fulda-Göttingen, Germany	230 km/h	Mono-block sleepers, lowered ballast	Winter conditions, snow	
2003	KTX	South Korea	300 km/h	Mono-block sleepers	No snow	See [Kw03] for details
2003	ICE 3	Lille-Calais, France	320 km/h	Bi-block sleepers	Winter conditions, snow	
2003	ICE 3	Belgium	300 km/h	Mono-block sleepers, ballast not lowered	No snow	Speeds up to 275 km/h did not cause problems in double traction
2004	ICE 3	France	320 km/h	Bi-block sleepers	No snow	During homologation test runs
2004	ICE 3	Mannheim-Stuttgart, Germany	250 km/h	Mono-block sleepers, lowered ballast	Winter conditions, snow	Foreign parts in the track have been found
2004	ETR 500	Rome-Naples, Italy	300 km/h	Mono-block sleepers, ballast not lowered	No snow	New tack with ballast above the sleepers, see Fig 4.2.3
2006	ICE-T	Hamburg-Berlin, Germany	230 km/h	Mono-block sleepers, lowered ballast	Winter conditions, snow	

The following sections give additional details of incidents and the current status of ballast projection measures in different European countries.

5.2.2 Italy

During initial runs of the ETR 500 on the then newly constructed Rome-Naples high speed line in 2004 a ballast projection incident occurred. The sleepers were of the mono-block type, as shown in the photograph in Figure 1 taken at the time of the incident. It can be seen that the ballast was not specially lowered between the sleepers, and significant amounts lay on top of the sleepers themselves.

On the first high speed line, the 25 kV Turin-Milan route, problems arose for 300 km/h running of the ETR 500. Three levels of ballast height reductions were investigated with ballast impacts being monitored using microphones. The best ballast level was chosen for the maintenance target. Maintenance procedures were modified to ensure that ballast stones are properly placed, but the intervals between track maintenance have not been increased. Since the initial problems, there have been no further problems with flying ballast for trains regularly running up to the maximum speed of 300 km/h. Homologation for the ETR 400 (also known as ETR 1000) running above 300 km/h required special measures and configurations of track to ensure test running up to 360 km/h without problems.

There are no national notified technical rules for ballast projection in Italy. If ballast projection occurs, the operator of the train has to establish a settlement with the infrastructure manager.

Figure 1 — Part of the Rome-Naples line at the time of the ballast projection incident in 2004, [1]

5.2.3 Spain

Railway Gazette (2005) stated that Spanish Development Minister Magdalena Álvarez, when presenting a report in March 2005 to the Spanish Parliament on difficulties encountered with the Madrid - Lleida section of the Madrid - Barcelona high speed line, that train operations at speeds greater than 300 km/h caused ‘ballast particles to be sucked up and thrown around’.

The Universidad Politecnica Madrid and Adif have studied ballast projection since 2008. Preliminary studies were undertaken in 2008-2010, followed by the AeroTRAIN Project (2010-2012), and then the Aurigidas Project (2012-2014). In all of the projects, detailed measurements of surface loads and induction phenomena were undertaken with ballast risk projection analysis. These were followed by Norm definition studies in 2015-2017. A national guideline on the issue is being prepared by Adif.

5.2.4 France

In France, the major incident of ballast projection occurred in 2003 and 2004 during homologation tests of the ICE3 running at 320 km/h (single unit). Damage to the train and the track was very significant and of a magnitude never seen to TGVs or other high speed trains running in France, even at higher speeds. Following this, different types of studies were carried out by German and French personnel to understand the origin of these incidents and to try to avoid or at least limit them.

As a result of this work, the underbody of ICE3 running in France was modified and tests were carried out (air speed measurements in the track bed during train passing, microphones, video control, underbody inspection) in 2005, to check the behaviour of the modified train regarding ballast projection. These tests confirmed the decrease of the aerodynamic load on the track and the frequency and intensity of ballast projection.

A review of ballast incidents was carried out after one year of operation. Several incidents were identified, but have always been observed during cold weather (temperature close to zero and snow) in Germany.

Due to these incidents, for all new high speed trains running in France or for test running at speeds above 320 km/h, some specific monitoring has been required since 2004 on the trains< (accelerometers or microphones for stone impact counting and video control), and air speed measurements in track have to be made for all new high speed trains.

A French regulation, SAM X 012 [4], was published by EPSF in 2015 to describe the methodology to assess a new high speed train regarding ballast projection. This methodology is based on air speed measurements in the track and consists of comparing the new train with an existing train or with an absolute criterion (cf § 7.2).

In France, ballast projection also occurs in winter due to snow/ice conditions. To limit these incidents, speed reductions are applied on French high speed lines.

5.2.5 Germany

The major incident of ballast projection of concern to Germany actually occurred not in Germany, but in Belgium, during homologation tests on the ICE 3 on a new high speed line. The ICE 3 had run without incident on high speed lines in Germany. The Belgian high speed line was fitted with mono-block sleepers, but no ballast lowering had been instigated. Successful trials had taken place with single traction units of 200 m length running at up to 300 km/h. However, when the double units were running at 270 km/h, ballast impacts on the train underside were audible. During one run severe damage occurred to the train underside, which led to Siemens having to investigate improved underbody designs to limit the problem.

Passenger reports on 15 Jan 2016 stated that an ICE travelling from Stuttgart to Frankfurt was hit hard by ballast stones. The incident was reportedly caused by ice lumps dropping from the train. Damage was caused to the train under-floor surfaces and side windows were cracked. The train continued at reduced speed. (SOURCE: https://rail-sim.de/forum/index.php/Thread/20576-Bahn-reduziert-H%C3%B6chstgeschwindigkeit-im-Fernverkehr/?pageNo=3:).

5.2.6 Great Britain

However, the High Speed 1 line (HS1) in Great Britain, runs from London to the Channel tunnel, and Eurostar trains using the line reach a top speed of 300 km/h. A form of rail damage, known as 'ballast pitting', has been reported, but no ballast projection problems have. This type of damage appears to be associated with small particles of ballast becoming trapped between the railhead and the wheels of rail vehicles. It is thought that the speed and the energy of trains cause an explosive crushing of the ballast particle, which damages both the railhead and the wheel. Inspection and maintenance records of train wheels on HS1 show that wheel pitting occurs predominantly on the front and rear bogies of a train with a steady reduction towards the centre of the vehicle. Quinn et al [2010], suggest that the vibrations and pressure pulse associated with the approaching train play a part in making ballast particles airborne as the trains travel in the reverse direction on the return journey.

High Speed 2 is a new line soon to begin construction in 2019, and will have a design speed of 360 km/h and an operating speed of 330 km/h. Obviously, there are no ballast projection problems on this line.

5.3 Overview of ballasted track systems in Europe

5.3.1 General

There are several aspects of the design of ballasted track directly under passing trains, which may be relevant to the issue of aerodynamically induced ballast projection. These are:

- sleeper type and sleeper spacing;
- rail fastening systems, and whether these provide restraint to ballast movement;
- ballast size;
- ballast maintenance procedures.

How these aspects vary in different European countries could have an impact on risk of ballast projection on different railway infrastructure designs.

5.3.2 Sleepers

There are a number of different types of sleepers, which are used in varying proportions by European railways. They are used to support the rails in position on the ballast bed and are generally of similar sizes, and differ mostly in their construction materials. These are summarized in Table 2.

Table 2 — Common sleeper types used on European ballasted track.

Sleeper material	Size	Notes
Timber	Typically, 150 mm high, 250 mm wide	Different types of wood can be used. Ballast longitudinal movements restricted by the sleeper, unless ballast above sleeper level
Steel	Similar size to wooden sleeper.	
Concrete mono-block	Similar size to wooden sleeper.	Ballast longitudinal movements restricted by the sleeper, unless ballast above sleeper level.
Concrete twin- or bi-block		Consists of two blocks connected by a coupling rod or pipe to maintain separation of blocks. Ballast free to move longitudinally between blocks.

Of particular interest is the bi-block sleeper, where there is no constraint to the movement of the ballast in the direction of the train from the sleeper between the two end blocks.

Examples of the different sleepers are shown in Figure 2.

The sleeper spacing, which for instance varies between 600 mm and 800 mm in Great Britain, depends on the axle loading of trains using the line, track curvature and whether there are local track formation difficulties. This is to ensure the vertical and lateral stability of the track. Due to sleeper functionality, there is unlikely to be any systematic difference between European countries in sleeper spacing, although within a country there could be differences between lines depending on the factors above. For high speed lines, it is expected that differences in sleeper spacing between countries will be relatively small, (as axle loads will be similar, track formation will be of high quality and track curvatures will be larger than on conventional lines).

a) Wooden sleepers b) Steel sleepers

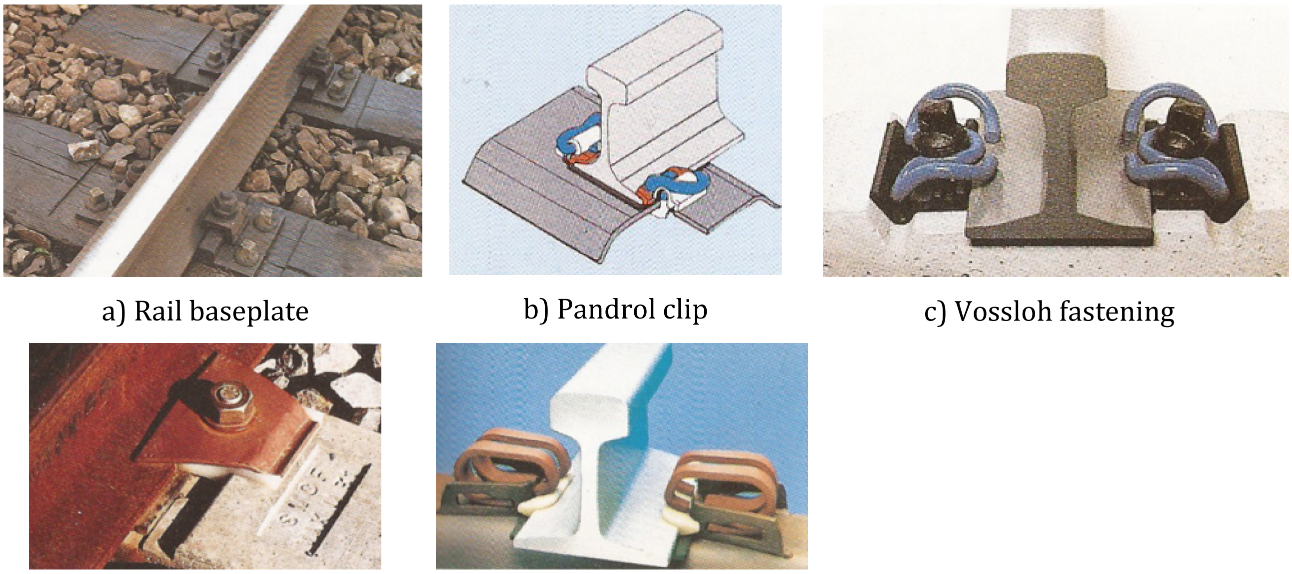
c) Mono-block sleepers d) Bi-block sleepers

Figure 2 — Examples of railway sleeper types

5.3.3 Rail fastenings

Rail fastening are used to secure the rails to the sleepers and there are a number of different designs currently in use. Baseplates may be also used under rails to hold the rails in place and may be used in conjunction with clip devices.

The DE (Deenik, Eisses) clip, shown in Figure 2 a), is widely used and can be fitted on concrete or wooden sleepers. A number of manufacturers have also produced other fastening devices, such as Pandrol, Vossloh, McKay, and Nabla. These other devices are shown in Figure 3.



a) Rail baseplate

b) Pandrol clip

c) Vossloh fastening

d) McKay fastening

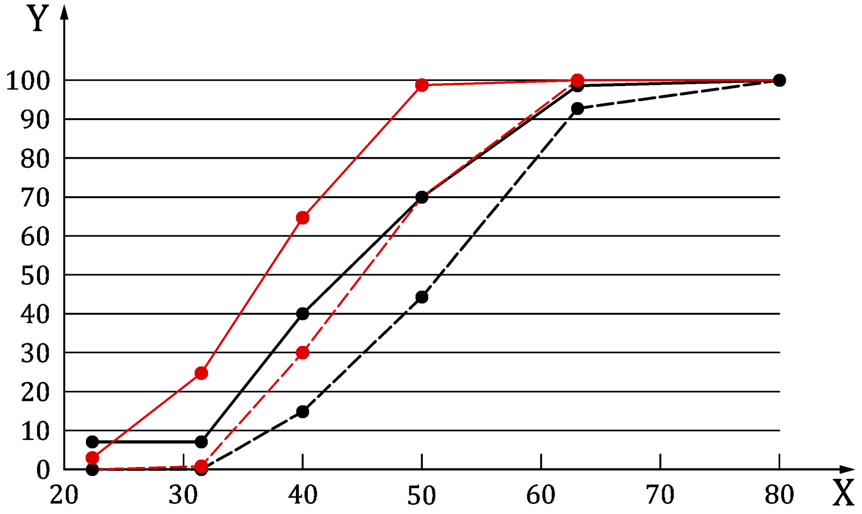
e) Nabla fastening

Figure 3 — Rail fastening systems

It can be observed that the rail fastening systems, although having differing designs, are unlikely to influence ballast movement or provide any significant impediment to aerodynamic ballast projection.

5.3.4 Ballast Size

EN 13450:2013 *Aggregates for railway ballast* is a standard which specifies a standard for railway ballast sizes. Although currently withdrawn, the standard is still referenced in company standards e.g. by Network Rail in Great Britain. Essentially, ballast is graded according to the mass of ballast which passes through sieves with holes of varying sizes. Ballast particles range between a nominal 31,5 mm up to a maximum of either 50 mm or 63 mm. Within each of these ranges there are three sub-ranges referred to as grading categories, A to F overall. Figure 4 shows grade category A in the range up to 50 mm, and grade F in the range up to 63 mm, and represents the full range of ballast sizes and distributions. For each grade category there is also a further sub-range at each sieve size, indicated by a solid line at the maximum value and a chained line at the minimum. It can be seen that most ballast particles are between 20 mm and 63 mm, whichever grade of category they are in.



Key

X sieve size, mm

Y percentage passings by mass

● cat A

● cat B

Figure 4 — Distribution of ballast sizes, Categories A and F

Ballast is maintained using a number of machines, such as stone blowers. These use smaller ballast particles, capable of passing through a 20 mm sieve, which are blown under the sleepers once the machine has lifted them, to maintain the track level. At worst, 80 % of this type of ballast will be large enough to pass through a 14 mm sieve. It is possible that these sized particles can find their way to the surface of the ballast bed.

There is no evidence known to the authors of systematic ballast size and shape distributions being different in different European countries.

5.3.5 Ballast maintenance regimes

5.3.5.1 General

An important consideration for aerodynamic ballast projection is where ballast is permitted to lie between the running rails, which will depend on the maintenance regime for high speed lines in each country.

5.3.5.2 Great Britain

5.3.5.2.1 Network Rail

A variety of railway sleepers are used on the standard railway lines in Great Britain. These include wooden sleepers, concrete mono-block sleepers and steel sleepers. Figure 5 shows a still image from a Network Rail ballast maintenance video; ballast stones can be seen on the sleepers, despite the commentary stating “No ballast must be left on the railhead, piled against the rail webs, over the fastenings or *loose on the sleepers*”. It is not clear if the instruction was eventually complied with in the video.

Figure 5 — Still from Network Rail video on ballast maintenance

5.3.5.2.2 High Speed 1

High Speed 1 is constructed using twin-block concrete sleepers on plain line and mono-block pre-stressed concrete sleepers in the- vicinity of turnouts and switches. It uses a mixture of ballasted and slab track.

5.3.5.2.3 High Speed 2

High Speed 2 will be constructed with a mixture of slab track and ballasted track. No information has been obtained regarding the sleeper types to be used.

5.3.5.3 Germany

German infrastructure managers established a procedure to counteract damage by ice dropping instigating ballast projection. In late autumn the height of ballast is checked and lowered by a sweeping machine to 4 cm to 6 cm below the base of the rail. This maintenance work is performed according to internal rule 820.2010 7 (6) for every railway line above 140 km/h except for curves with small radius. As sleepers are then elevated compared to the ballast bed level, objects dropping from fast running trains will most likely hit the sleeper only, due to their flat-angle trajectory. The impact on sleepers is acceptable and avoids the swirl of further ballast stones from the ballast.

5.3.5.4 CER position paper

In 2015, the Community of European Railway and Infrastructure Companies (CER) and European Rail Infrastructure Managers (EIM) produced a joint position paper on aerodynamic ballast projection, CER/EIM (2015). This specifically addressed the open points relating to ballast projection in the LOC&PAS and INF TSIs and set out some principles that were felt should be respected when regulating for the issue. The paper acknowledges the full-scale track test procedure for the assessment of rolling stock set out in Annex A of EN 14067-4:2013+A1:2018 *Railway applications - Aerodynamics - Part 4: Requirements and test procedures for aerodynamics on open track*, but notes the absence of limit values or acceptance criteria. It notes and does not oppose the philosophy espoused in EN 14067-4 of the