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BALLAST CONDITION EVALUATION DURING TAMPING ACTIONS

Stefan Offenbacher[1], Matthias Landgraf[1], Bernhard Antony[2]
[1] *Institute of Railway Engineering and Transport Economy, TU Graz, Austria*
[2] *Plasser & Theurer, Export von Bahnbaumaschinen, Gesellschaft m.b.H., Austria*

Abstract

Ballast is a key component of most railway tracks. The ballast bed must cope with high demands while fulfilling crucial tasks. Wear and contamination cause the condition of the bedding to deteriorate, which is accompanied by a loss of its proper functioning. Consequently, track alignment issues arise, which are typically corrected by tamping the affected areas. This study presents a new approach to assess the condition of the bedding. The tamping unit of a high-performance tamping machine has been equipped with an array of sensors which measure various parameters during every tamping process. A set of recorded data is analysed and compared with the prevailing ballast condition of the tamped sections, which is evaluated using proven methods. The results indicate a strong correlation between the tamping machine measurements and the condition of the bedding, which shows that tamping machines can be used to monitor the track ballast condition.

Keywords:

1 Introduction

Globally, most railway lines feature a conventional track structure [1] where the main components are rails, sleepers, and track ballast. A well-functioning ballast bed strongly contributes to track elasticity, distributes the induced forces in longitudinal and lateral direction and fosters water runoff. The bedding also secures the track grid (rails + sleepers) in its position and thereby largely defines the overall track geometry. The desired properties of the bedding lessen over time due to its contamination and wear of the stones. Consequently, load distribution within the track structure changes adversely and track geometry problems occur [2]. These, in turn, increase the dynamic forces caused by passing trains, which exacerbates the problem. This vicious circle highlights the importance of a well-maintained ballast bed, which implies the necessity of proper condition monitoring. While several methods for ballast condition monitoring exist, two are particularly well-suited for net-wide evaluations: ground penetrating radar (GPR) and fractal analyses [3]. However, both of them are indirect measurements – both assess the condition without coming into contact with the bedding. This makes the two methods susceptible for inadvertent external interferences.
This study presents a novel alternative for ballast condition assessment, using data recorded by a tamping machine while operating in the network of Austrian Federal Railways (ÖBB). Besides analysing this tamping machine data, the sections where the tamping works were conducted are also thoroughly investigated. The prevailing ballast condition on these sections is assessed via a ballast condition index, which combines GPR and fractal analyses. This ballast condition index serves as reference to which the tamping data are then compared.

2 Methodology

This study is based on two different data sources: The data recorded by the tamping machine – hereinafter referred to as “tamping data” – are provided by Plasser & Theurer, Export von Bahnbaumaschinen, Gesellschaft m.b.H. Information of the infrastructure – hereinafter addressed as “infrastructure data” – is provided by the Institute of Railway Engineering and Transport Economy (Graz University of Technology). This chapter describes the two data sources and how they are connected.

2.1 Infrastructure data

The infrastructure database of the Institute of Railway Engineering and Transport Economy covers a large part of the ÖBB network. The data warehouse comprises general information (e.g. line speed, track load, curvature), superstructure parameters (e.g. track age, rail profile, sleeper type), and track recording car measurements over multiple years. Regarding the ballast condition, GPR evaluations and fractal analyses (derived from the longitudinal level signal) are incorporated. Within this study, all assessments of the infrastructure along the tamping sections rely on this infrastructure data base.

2.1.1 Track ballast condition

New track ballast consists of rough-edged stones which form a strong, interlocked matrix with vacant space between the stones. This structure gives the bedding its desired properties [2]. When the stones abrade or even break under the high loads of rail traffic, the voids get contaminated with fine grain (Fig. 1). Small particles can also originate from external sources (e.g. leaking coal waggons) or rise from the substructure [4]. The condition of the bedding can be assessed with different methods, two of which are applied in this study: ground penetrating radar and fractal analyses.

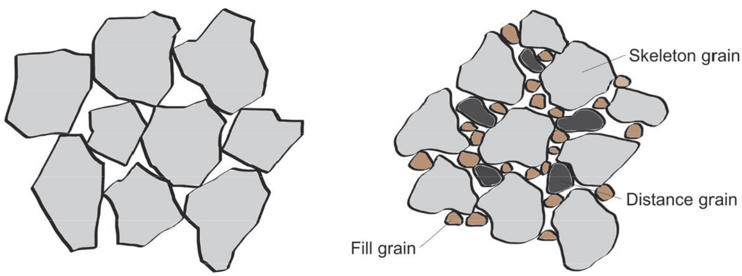

Figure 1 Illustration of the difference between clean new ballast versus worn and fouled ballast [5].

Ground penetrating radar (GPR) uses electromagnetic pulses which are emitted towards the track. Depending on the material and the condition of the evaluated structure, these pulses are absorbed and reflected to certain degrees. The discrepancies between the emitted and the received pulses enable assessments of the targeted objects – in case of track monitoring the ballast bed and the substructure [6].

Fractal analyses are a mathematical concept used for signal analysis. In the context of railways, the longitudinal level signal is dissected into three fractal dimensions. These dimensions represent short-waved, mid-waved, and long-waved track irregularities. Studies have shown that the mid-waved fractal dimension strongly correlates with the condition of the bedding; thus, using the mid-waved range, fractal analyses are well-suited to assess the ballast condition [7].

2.1.2 Ballast condition index

Landgraf [3] developed a ballast condition index which combines GPR evaluations and fractal analyses. This methodology provides a holistic assessment of the ballast condition and it serves as reference parameter in this study. Compared to the individual methodologies (GPR, fractal analysis), the ballast condition index offers two main advantages: First, it rates the ballast condition at any point in the network by a single value ranging from 0 % (worst condition) to 100 % (best condition). Otherwise, several GPR categories (such as ballast fouling, ballast humidity, or clay fouling) and multiple available fractal evaluations (one for every measurement car run; typically, four runs per year are conducted on main lines) would have to be considered separately. Secondly, the combination of ground penetrating radar and fractal analyses strengthens the validity of the results. Individually, both methodologies underly unavoidable variances caused by influences beyond control. The ballast condition index will only take on high (good condition) or low (poor condition) values if the two methods are conform with each other, i.e. if both assess the ballast condition either good or poor. These extrema are in the focus of the present study. Should the GPR and fractal analyses contradict each other, i.e. one methodology indicates good ballast condition and the other poor, the resulting condition value will be around 50 %.

2.2 Tamping data

The data recorded by the tamping machine originate from 13 tamping actions which were executed in the network of Austrian Federal Railways (ÖBB) in 2016 and 2017. During these tamping actions, approximately 10,000 tamping processes were conducted. A tamping process includes (a) positioning the tamping unit centrally above the sleeper and realigning the track grid, and (b) one to three consecutive squeezing processes. Each squeezing process consists of (i) penetrating the ballast bed, (ii) a squeezing movement, and (iii) lifting the tamping unit. During the entire process the tamping tines vibrate back and forth at a frequency of 35 Hz. [5]

The tamping data were recorded by four different types of sensors, all mounted on the same tamping arm and tamping tine (Fig. 2). Strain gauges on the tamping tine measure forces in vertical and horizontal direction, accelerators at the top of the tamping arm enable the calculation of the oscillation amplitude. A pressure measurement in the hydraulic system records any movement of the fluid and a laser rangefinder delivers the squeezing displacement [8].

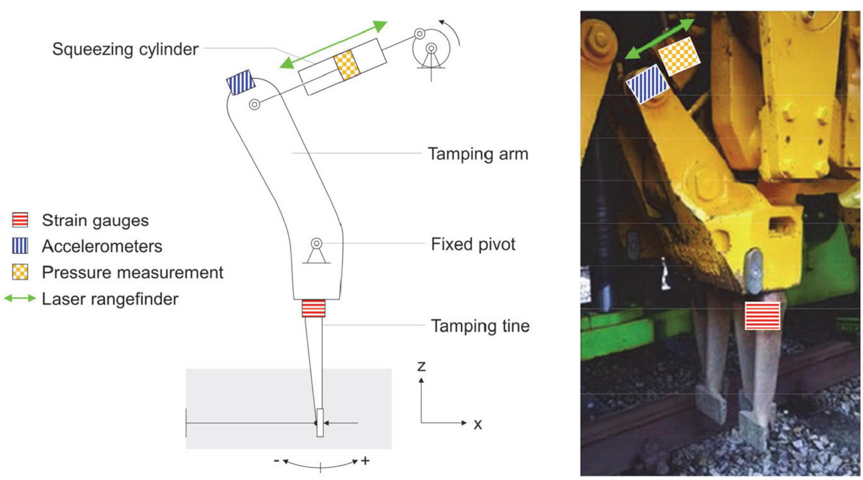

Figure 2 Positioning of the sensors on the tamping arm and tamping tine (adapted from [8]).

Six relevant parameters recorded the tamping machine are analysed in this study: penetration force, squeezing force, squeezing energy, squeezing velocity, loading response, and unloading response (see Table 1). Penetration force, squeezing force and squeezing velocity are directly measured; squeezing energy, which represents the energy that is transferred into the bedding, as well loading and unloading response, which represent the resistance of the ballast to the tamping tine movement, are calculated in retrospect. Each parameter is represented by one value per squeezing process. This value is either the maximum or the average of all tamping tine oscillations during the respective squeezing process.

Table 1 Description of the analysed tamping parameters.

Parameter	Unit	Description
Penetration force	kN	Maximum axial force (in z-direction; see Fig. 3) during ballast penetration.
Squeezing force	kN	Maximum lateral force (in x-direction; see Fig. 3) during the squeezing movement.
Squeezing energy	J/s	Standardized consumed energy per squeezing movement (average of all tine oscillations).
Squeezing velocity	mm/s	Velocity of the closing tamping tines (average of all tine oscillations).
Loading response	MN/m	Ballast response during the forward oscillation of the tamping tines (average of all oscillations).
Unloading response	MN/m	Ballast response during the backward oscillation of the tamping tines (average of all oscillations).

2.3 Data connection

Before the recordings of the tamping machine can be analysed for correlations with the ballast condition, the tamping data set needs to be linked to the infrastructure data set. This is possible via GPS coordinates, which the tamping machine recorded at every tamping process. This results in one recorded position every 2.4 m, as the machine in question is a 4-sleeper main line tamping machine and the average sleeper gap is 60 cm. In contrast, the infrastructure database provides track coordinates with intervals of 1 m. Therefore, every coordinate recorded by the tamping machine needs to be linked to its counterpart of the infrastructure data base. Fig. 3 shows an illustration of how this process is done: for every coordinate recorded by the tamping machine, the nearest coordinate of the infrastructure data base is extracted. All information of this coordinate pair – infrastructure data and tamping data – is then merged. This connected data set constitutes the basis for all further analyses.

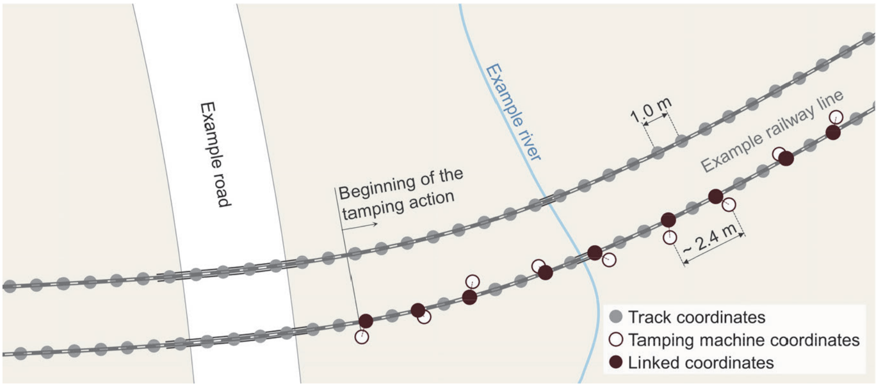

Figure 3 llustration of the connection process which links tamping machine coordinates to track coordinates.

3 Results

Having connected the two required data sets, the sections where the tamping actions took place are inspected. During the 13 recorded machine deployments approximately 6 km track was tamped. Almost 50 % of the executed sections were equipped with concrete sleepers, ~30 % with concrete sleepers with under sleeper pads (concrete USP), and ~20 % with wooden sleepers.

The tamping actions were partly performed in course of complete track renewals and partly as part of the regular track maintenance program (Fig. 4). On main lines, track renewals generally include a ballast cleaning, which invalidates any information on previous ballast condition. Thus, track renewal tamping actions are excluded from further analyses. The remaining maintenance tamping actions were largely executed on sections with concrete sleepers (~2.7 km). Therefore, they constitute the largest individual sample and will be analysed in detail.

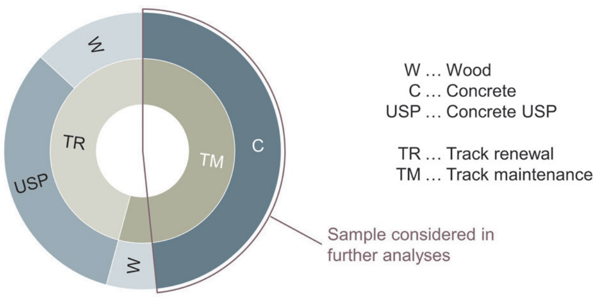

Figure 4 Share of the tamping types (track renewal and track maintenance) and sleeper types.

Fig. 5 gives an overview of the ballast condition along the tamping sections (track maintenance; concrete sleepers), expressed via the ballast condition index. The histogram bars represent the relative frequency of tamping processes (which is proportional to the track length) executed at a specific ballast condition.

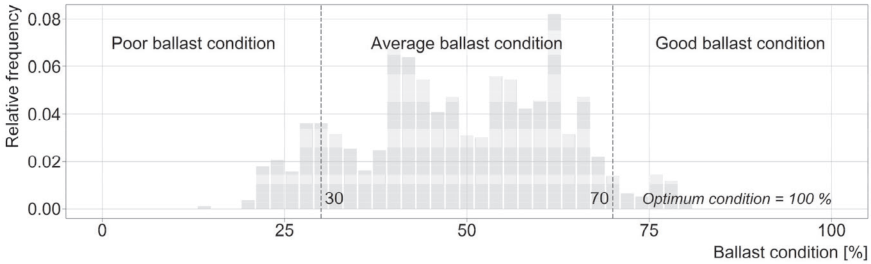

Figure 5 Histogram depicting the relative frequency of tamping processes perfomed at different ballast condition levels.

For comparison with the tamping data, the ballast condition values are clustered into three groups: poor ballast condition, average ballast condition, and good ballast condition. The threshold values separating these groups are set at 30 % and 70 % of the condition index. Thus, only if both GPR and fractal analyses rated a point either good or poor they will end up in the good or poor cluster. The majority of data is categorized as average condition; this includes any point which the two evaluation methodologies (GPR, fractal analysis) have assessed differently.

The recorded tamping data are presented in Fig. 6 in form of boxplots, clustered into the three condition groups good-average-poor. The measurement values are normalized, i.e. the lowest recorded value equals 0 % and the highest recorded value equals 100 %. The general overlapping of the boxplots between the three ballast conditions is a result of many influences, which further research needs to investigate. Presumably, variances of the underlying data and offsets between the tamped sleeper and the connected track point (see Fig. 3) affect the results. Also, the ballast condition index does not provide the precise ballast condition like wear of the stones, humidity level, contamination level, or types of contaminants. However, suchlike parameters may affect the tamping machine measurements. Despite the aforementioned uncertainties, the plot in Fig. 6 demonstrates that all tamping parameters (except unloading response which will be investigated in future research) significantly differ between the different ballast condition groups, which is marked by the non-overlapping notches of the boxplots. This proofs that the tamping machine measurements correlate with the ballast condition – or in other terms, it is possible to assess the condition of the bedding with tamping machines during track works.

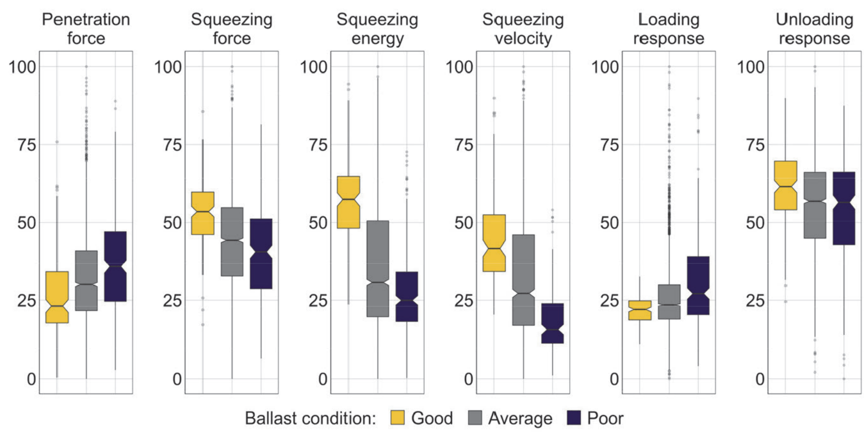

Figure 6 Boxplots of the normalized tamping parameters (lowest recorded value = 0 %, highest recorded value = 100 %), clustered into good, average, and poor ballast condition.

4 Conclusion

This study investigates whether tamping machines, upgraded with an array of sensors attached to the tamping unit, can be used to assess the condition of the bedding during tamping works. A tamping machine has been equipped with multiple sensors which measure different parameters during every tamping process. Data recorded by these sensors during 13 tamping actions in the Austrian railway network are analysed. Simultaneously, the prevailing ballast condition along the tamped sections is evaluated using ground penetrating radar and fractal analyses. The two data sets – tamping machine recordings and ballast condition information – are then linked and thoroughly analysed. The results show a clear correlation between the tamping machine measurements and the prevailing ballast condition. This provides evidence that tamping machines, upgraded with a smart sensor system, are able to evaluate the condition of the ballast bed.

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