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In-situ measurements and a semi-analytical approach to ballast bed modelling during compaction

Mjerenja in-situ i semi-analitički pristup modeliranju tucanika tokom podbijanja

Olja BARBIR[1], Dietmar ADAM[2], Fritz KOPF[3], Johannes PISTROL[4], Florian AUER[5], Bernhard ANTONY[6]

Throughout the world, the condition of the ballast bed is one of the most important parameters for a safe and economical operation of railway systems. Better knowledge of ballast condition provides an advantage in defining the optimum time for ballast bed cleaning or renewal. Tamping process is the core maintenance activity in ballasted track and it is crucial to the economical service life of the track and essential in restoring the track geometry for safe train operations. During the tamping process, the tamping tines interact with the ballast matrix, transferring the displacement caused by the dynamic excitation overlapped with the extension in the hydraulic cylinder to the ballast, compacting it under the sleeper. This interaction is observed and measured in-situ within the framework of this research project. Serving as a mean of comparison and confirmation with the conducted in-situ measurements, a semi-analytical model of the tamping unit – ballast matrix interaction has been developed.

Keywords: track tamping, track ballast compaction, semi-analytical ballast modelling

Sažetak

Stanje tucaničkog zastora uvelike utječe na sigurnost i ekonomičnost prometovanja vlakova na određenoj trasi. Informacije o stanju tucanika omogućile bi točnije definiranje optimalnog trenutka za provođenje podbijanja kolosijeka ili pročišćavanja kolosiječnog zastora. Proces podbijanja pruge odnosno tucanika ispod pragova aktivnost je od presudnog značaja za vraćanje pruge u njezin prvobitni položaj, produžavajući tako njezin vijek trajanja. U okviru ovog znanstvenog projekta interakcija krampova podbijačice i tucanika promatrana je i mjerena in-situ. Semi-analitički model ove interakcije razvijen je s ciljem potvrđivanja točnosti rezultata mjerenih in-situ, kao i provođenja studije parametara za optimizaciju procesa podbijanja.

Ključne riječi: podbijačice tucanika, optimizaciju procesa podbijanja, semi-analitičko modeliranje

[1] Dipl.-Ing., TU Wien, Vienna; olja.barbir@tuwien.ac.at

[2] Univ.Prof. Dipl.-Ing. Dr.techn., TU Wien, Vienna; dietmar.adam@tuwien.ac.at

[3] Priv.Doz. Dipl.-Ing. Dr.techn., FCP Fritsch, Chiari & Partner ZT GmbH, Vienna, kopf@fcp.at

[4] Dipl.-Ing. Dr.techn. BSc, TU Wien, Vienna; johannes.pistrol@tuwien.ac.at

[5] Dipl.-Ing. Dr.techn., Plasser & Theurer, Vienna; florian.auer@plassertheurer.com

[6] Dipl.-Ing. BSc, Plasser & Theurer, Vienna; bernhard.antony@plassertheurer.com

Introduction

The operating principle of a tamping machine i.e. tamping unit (Figure 1) is lifting the track up to the level determined by previous measurements and simultaneously position it laterally. Once the track is in the intended position, the tamping tines penetrate the ballast and the tamping process begins. The squeezing movement begins subsequently and is defined as a closing movement of the tines around the sleeper with the objective of refilling the gap created beneath the sleeper and compacting the ballast. The non-synchronous tamping principle, in which the tamping is performed, described as movement of all tamping tines with the same force, independent of the path, together with directional vibrations, ensures a uniform ballast compaction.

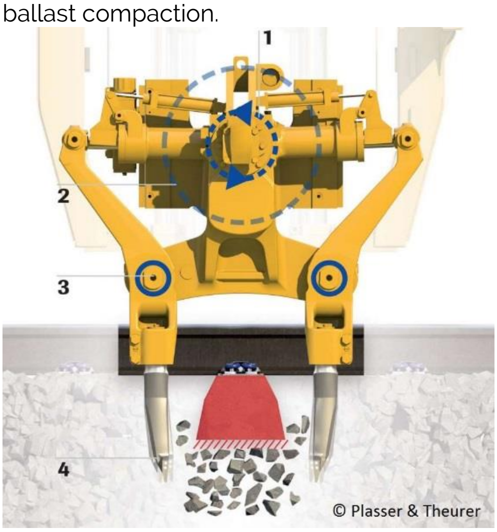

Figure 1. Tamping unit lowered into work position: (1) Vibration by eccentric shaft, (2) Power reserve from balance weight, (3) Fixed pivot, (4) Stable amplitude

Experimental approach

In the scope of this research project tamping machine Dynamic Tamping Express 09-4X E^3 was equipped with a number of strategically positioned sensors in order to perform the in-situ measurements required to describe the interaction of the tamping tine with the ballast and its compaction beneath the sleepers. Strain gauges are applied and used for measuring the lowering forces and lateral tine forces. Accelerometers placed on the upper point of the tamping arm allow a precise calculation of the tine oscillation amplitude in a local coordinate system. Together with the pressure and elongation measurement at the hydraulic cylinders the tamping process can be fully documented and subdivided. The tamping process begins as the tamping unit reaches an exact position above the sleeper and is continued by following categories (Figure 2):

- ballast penetration (1)
- squeezing movement (2)
- lifting of the tamping unit (3)
- tamping unit reloction to the next sleeper

Tamping process subdivision allows a determination of energy consumption per category, with a special emphasis on the squeezing movement that contributes mainly to the ballast compaction.

Operation of the Dynamic Tamping Express 09-4X E^3 was monitored at different locations in Austria by means of the measuring system described above, resulting in an extensive series of collected measurement data.

Experimental results

An initial approach towards successful data analysis implies a newly developed method of dynamic measurement analysis (Plasser Theurer, 2017), the load-displacement curve i.e. lateral force-oscillation displacement diagram, presenting a single cycle during the tamping process (Figure 3). This presentation allows an insight into seven tamping parameters essential for a successful data evaluation:

- oscillation amplitude
- maximal lateral force
- ballast matrix stiffness/response during loading and unloading
- energy transferred into the ballast
- points of tamping tine - ballast contact (begin and loss of contact)

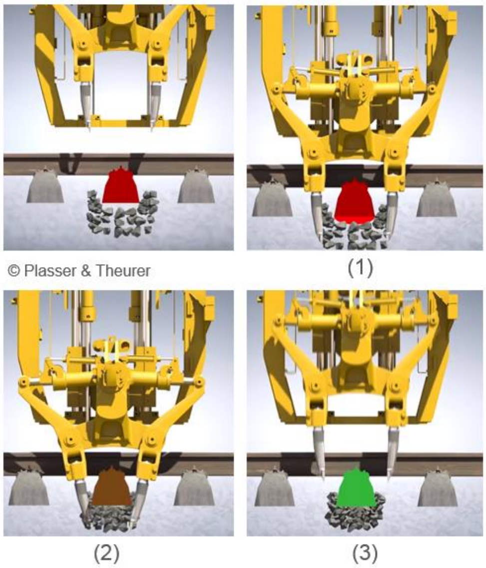

Figure 2. Tamping process subdivision

Depending on the observed part of the tamping process, the load-displacement curve can take several different shapes. During initial contact, while penetrating the ballast, the diagram displays a typical elliptical shape, caused by the unsymmetrical shape of the tine. In the course of a squeezing movement the tamping tines squeeze the ballast beneath the sleeper forming a typical curve, as can be seen in Figure 3 (below). The eccentricity of the curve is attributed to the squeezing velocity, where the negative share of the curve would decrease with the increase of velocity. However, the velocity has to be kept under certain limits for the tamping tine to remain in contact with the ballast for the time required for the energy to be transferred (minimal required impulse duration) (Fischer 1983).

Graphical and statistical data analysis

Considering the extent of the collected and analysed data, a development of a stable and reliable algorithm for data analysis was necessary. All of the data sets assembled during the measurements were analysed both graphically and statistically.

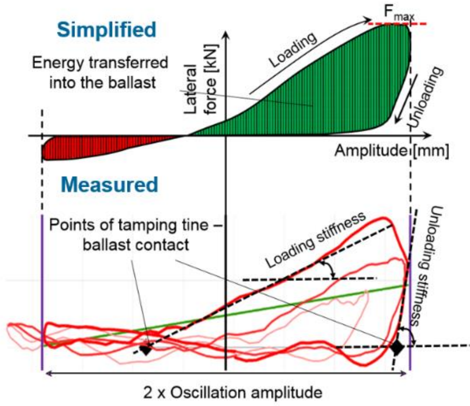

Figure 3. Simplified load – displacement curve (above), and the curve as a result of the conducted measurements (below) (Barbir et al. 2018)

Depending on the squeezing time, every squeezing movement, preformed with a 35 Hz frequency (Fischer, 1983) consists of a certain number of cycles (load-displacement curves). In order to have a complete insight into every cycle or to see how the energy of compaction and the loading stiffness of the ballast change during the squeezing movement, the so-called waterfall diagram is composed (Figure 4, left). This graphical presentation allows a general comparison of two different data sets (i.e. two different ballast conditions), as well as an overview of ballast compaction progress during one squeezing process. Additionally, heat maps of the above-mentioned diagrams are constructed. A heat map is a graphical representation of data where the individual values contained in a matrix are represented as colours. Figure 4 (right) shows a “top view” of the waterfall diagram, where the force is presented in a colour scale, and the contour lines (i.e. isolines) connect areas of the same particular value. As the ballast compaction progresses, the needed force as well as the area within the load-displacement loop increases. As a second confident indicator of ballast stiffness increase, the enhancement of loop steepness can be noted, indicated by a decrease of distance between the contour lines. Additionally, points showing the begin and end of tamping tine – ballast contact are depicted overlaying the heat map. This

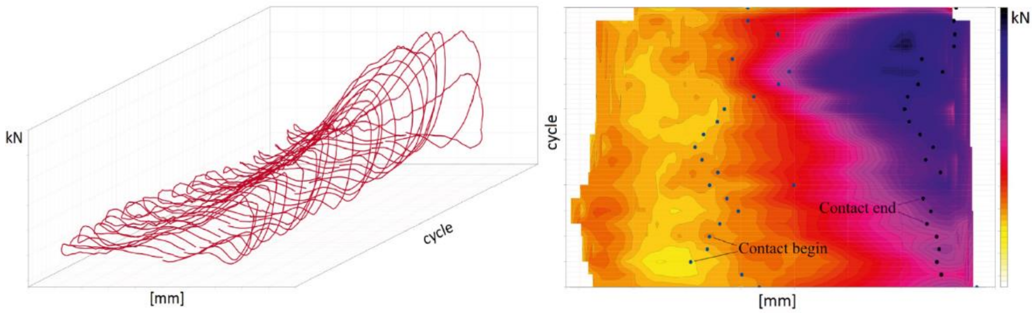

Figure 4; Waterfall diagram, showing stacked consecutive load–displacement loops (left), Heat map, showing stacked consecutive load–displacement loops together with points of tamping tine-ballast contact beginning/end (right) (Barbir et al. 2018)

presentation allows a quick insight into ballast particle movement between two cycles. In every following cycle, the tine reaches the ballast later than in the preceding one, indicating a residual plastic deformation, i.e. ballast compaction.

Statistical analysis is conducted for all of the tamping parameters stated, stating noticeable differences between track maintenance conducted in new and fouled ballast conditions. Significantly higher values of maximal lateral force per cycle are measured during fouled ballast compaction. Taking into consideration that the amplitude of oscillation is kept constant, the lateral force has a direct influence on the total transferred energy during a squeezing movement that doubles in value if comparing fouled and new ballast conditions. The differences in the ballast stiffness measured is additionally confirmed by the shape of the load-displacement diagrams for different ballast conditions, showing changes in ballast behaviour and movement during and between cycles.

Semi-analytical model of the tine – ballast matrix interaction

Succeeding the analysis of in-situ collected data, the interaction between the tamping tine and the ballast matrix during compaction, i.e. during the squeezing movement is developed. The tamping unit is presented by a simple system of rods with a dynamic excitation overlapped by a hydraulic cylinder movement. Opening and closing of the cylinder is modelled with a variable rod length. The ballast matrix enclosed by the tines during compaction is based on a semi-infinite truncated cone for vertical translation (Wolf 1994, Pistrol 2016), the half space being represented by the Kelvin-Voigt model, which consists of a purely elastic spring and a purely viscous damper connected in parallel. The soil model is extended by an additional plastic spring, modelling the plastic deformation of the ballast matrix, i.e. its compaction under the sleeper. This semi-analytical approach is able to model both the displacement and force controlled motion of the tamping unit, as well as all three operating phases of the process:

- *loading* – tamping tine in contact with the ballast matrix, both elastic and the plastic spring are compressed.
- *unloading* – backward movement of the tamping tine, still in contact with the ballast matrix. The elastic spring stretches back, modelling the elasticity od the ballast matrix, while the plastic spring remains „locked“, modelling the remaining plastic deformation of the matrix, i.e. ballast compaction under the sleeper
- *withdraw* – tamping tine loses contact with the ballast matrix and reaches back before the next cycle begins.

This approach grants a possibility to model all of the different ballast conditions and phenomena measured in-situ, ranging from new and clean to the fouled ballast bed conditions, as well as a verification of the load-displacement curves.

Conclusion

In the scope of this research project, a comprehensive study of different ballast conditions is carried out in order to improve ballast serviceability. The in-situ collected data is used as a reference for the development of the ballast model described, assuring realistic representation of the in-situ condition. This semi-analytical application presents a reliable method of modelling non-cohesive soils, and can as such be implemented on other granular materials under dynamic loading.

References

Barbir e al., 2018. Development of condition-based tamping process in railway engineering, *XVI Danube - European Conference on Geotechnical Engineering*, Skopje, R. Macedonia

Fischer, J., 1983. Einfluss von Frequenz und Amplitude auf die Stabilisierung von Oberbauschotter (in German), *Doctoral thesis. Technical University Graz*, Austria.

Kopf, F., 1999. Flächendeckende dynamische Verdichtungskontrolle (FDVK) bei der Verdichtung von Böden durch dynamische Walzen mit unterschiedlichen Anregungsarten (in German). *Doctoral thesis, TU Wien*, Vienna, Austria

Pistrol, J., 2016. Verdichtung mit Oszillationswalzen (in German). *Doctoral thesis, TU Wien*, Vienna, Austria

Wolf, J. P., 1994. Foundation Vibration Analysis Using Simple Physical Models. *Prentice Hall*. Lausanne, Switzerland

Plasser Theurer, Export von Bahnbaumaschinen GmbH, 2017. Stopfen mit Verdichtungskontrolle - Verfahren und Vorrichtung zum Verdichten eines Gleisschotterbetts (in German), Patent submitted 29.05.2017 in Vienna, Austria