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XVII SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS
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DETERMINATION OF SLEEPER SUPPORT CONDITIONS

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Abstract *– Interaction between ballast bed and sleepers significantly influences track dynamic behaviour. Many investigations conducted in the field showed that more than 50% of installed sleepers can be considered as unevenly supported. In addition, investigations showed that unevenly supported sleepers often occur in a row and that this phenomenon leads to significant increase in dynamic forces in wheel-rail contact (increase up to 80% comparing to the sections with regular sleeper support). In current praxis, different methods for determination of sleeper support conditions were applied. This paper considers phenomenon of unevenly supported sleepers and it presents non-destructive determination methods.*

Keywords – track, ballast bed, sleepers, sleeper support conditions, non-destructive methods.

1. INTRODUCTION

Differential settlement of the ballast bed is an inevitable process that often causes irregular support of sleepers. In addition, this phenomenon could occur due to the embankment settlement. On the other hand, unevenly (partly) supported and unsupported sleepers (further referred as poorly supported sleepers) lead to ballast bed degradation and track geometry deterioration.

According to the research presented in [1], more than 50% of the sleepers could be considered as unevenly supported. Research conducted by Li and Sun showed that unevenly supported sleepers usually occur consecutively over 1-4 m of track [2], which was recently confirmed [3,4]. In addition, it was determined that void which occurs beneath the sleepers usually ranges from 2 mm to 4 mm [2,5].

Zhang et al. determined correlation between void height and vertical force in the wheel-rail contact, which applies for cases with up to 6 consecutive unsupported sleepers [6].

Ballast-sleeper interaction contributes significantly to the dynamic behaviour of the railway track [7]. Therefore, one or several consecutive poorly supported sleepers would lead to significant increase in dynamic influence. For example, dynamic forces in the wheel-rail contact could be up to 80% higher comparing to sections with good sleeper support [7]. When the wheel-rail contact force exceed yield strength of the rail steel it could lead to the origination and development of the rail defects due to the rolling contact fatigue [8-11].

Research conducted by Shi et al. considered influence of several cases of unsupported sleepers on the elements of track superstructure and substructure, track stability and ride quality using finite element model of the track. At first, they analysed track with good sleeper support. Afterwards, they used obtained results as a benchmark for cases with one to four consecutive unsupported sleepers. Following impacts were determined [5]:

- increase in the reaction force on the fastener: $R_1=1{,}35 \cdot R_0$, $R_4=3{,}20 \cdot R_0$,
- increase in the vertical acceleration of the vehicle: $q_2=1{,}35 \cdot q_0$, $q_3=1{,}69 \cdot q_0$, $q_4=2{,}38 \cdot q_0$,
- increase in the wheel-rail contact force: $P_1=1{,}03 \cdot P_0$, $P_4=1{,}12 \cdot P_0$,
- increase in the stress that transfers to the embankment: $\sigma_{b1}=1{,}01 \cdot \sigma_{b0}$, $\sigma_{b4}=1{,}60 \cdot \sigma_{b0}$,

where index i=0,1,2,3,4 (R_i, q_i, P_i and σ_{bi}) represents the number of consecutive unsupported sleepers.

On the other hand, irregular cross level leads to uneven stress distribution beneath the sleeper [12], which additionally contributes to the negative impact of poorly supported sleepers.

Research conducted by Lazarević et al. showed that deterioration of the vertical track geometry (longitudinal level) can be correlated with the sections of track with poor sleeper support [3,4].

2. METHODS FOR DETERMINATION OF SLEEPER SUPPORT CONDITIONS

Regarding previous considerations, it is obvious that

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determination of poorly supported sleepers in field is an important task for each Infrastructure Manager.

Determination of sleeper support conditions could be conducted using different methods. In general, these methods could be divided into direct and indirect methods. Direct methods provide the results related directly to the support conditions. On the other hand, indirect methods imply measuring parameters that are correlated to the sleeper support conditions, therefore providing the basis for indirect conclusions.

Regarding the in-field application, determination methods could be divided into continuous and manual (non-continuous) methods. Continuous methods imply application on network level using adequately equipped inspection vehicle. Non-continuous methods imply application on section level using manually propelled or portable devices.

It is important to state that there are pros and cons for each method. Therefore, responsibility of Infrastructure Manager is to choose the method that would provide reliable results, which provide the basis for creating the adequate maintenance plan.

3. DIRECT METHODS

Direct methods for determination of sleeper support conditions imply ballast bed scanning using acoustic waves [3], ultrasound [13], or ground penetrating radar (GPR) [14,15]. These methods could be applied both continuously and manually. For example, there are inspection vehicles equipped with GPR that are used on railway networks in Switzerland and Netherlands (Figure 1).

Fig.1. Inspection vehicle equipped with GPR on railway network in Netherlands

The most commonly used direct method is GPR, which is based on the principle that propagation of electromagnetic wave changes due to the passing from one medium to another. These changes are detected by the antenna, which digitally records the obtained signal.

Data collected using GPR cannot provide reliable results about sleeper support condition. The main problem with GPR is the calibration. On the other hand, electromagnetic waves reflect off the rails, reinforcement in sleepers, masts and similar steel structure, thus providing unreliable results.

4. INDIRECT METHODS

Indirect methods for determination of sleeper support conditions imply measuring sleeper vibration, vertical acceleration, velocity, deflection, or other parameters that could be correlated to the sleeper support conditions.

Kim et al. measured sleeper deflection on three sections of high-speed rail line in South Korea [16]. There were used three measurement methods in this research: a simple vertical deflection sensor, a modified falling weight deflectometer (as in Figure 2), and an optical system for deflection measurement. Analysis of the obtained results confirmed that poorly supported sleepers had larger deflections [16].

Fig.2. Sleeper deflection measurement using modified falling weight deflectometer

The vertical deflection could be determined by measuring vertical acceleration, and subsequent double integration of the obtained signal. This method was applied by Brajović et al. in the research conducted on 'TENT' railway network for coal transportation [17]. Figure 3 shows wireless sensor that was used in this research.

In addition, Brajović et al. investigated sleeper deflections on the same railway network using position sensitive detector fixed to the rail web (Figure 4). Same method was applied in the field research by Pinto et al. on the high-speed rail line in Portugal [18].

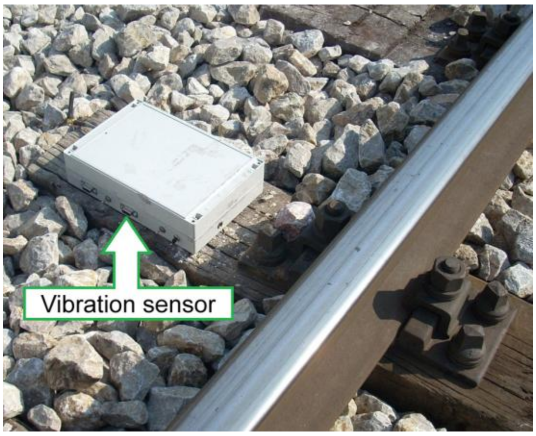

Fig.3. Wireless sensor for sleeper vibration measurements [17]

Fig.4. Position sensitive detector for sleeper vibration measurements

According to the definition of track stiffness [19], increase in the sleeper deflection would lead to the decrease in track stiffness. Therefore, track stiffness diagrams could be used for determination of track sections with poor sleeper support.

There are several types of devices that are used for continuous track stiffness measurements, such as rail-mounted devices (as in Figure 5) or devices that could be installed in the inspection vehicle [20]. These devices usually measure vertical force and acceleration, while deflection is calculated by double integration of the measured acceleration (as in [17]).

Fig.5. Rail-mounted device for track stiffness measurements used in UK [21]

However, it is necessary to state that track stiffness is not homogenous along the track [19]. First of all, stiffness diagrams are recognised by local maximum values that repeat regularly. These values correspond to the track stiffness beneath the sleepers [20]. On the other hand, abrupt changes in stiffness diagrams occur when device passes over track discontinuities, such as fish plate joints, isolated joints, expansion joints, transitions before and after bridges and culverts, switches, etc. Therefore, analysis of the stiffness diagrams and determination of sections with poorly supported sleepers demands detailed data about superstructure and substructure.

Sleeper support conditions could be determined using the analysis of sleeper dynamic response to the naturally or artificially induced excitation. The main idea of this method implies that poorly supported sleepers have significantly higher amplitudes comparing to the evenly supported sleepers [3,4].

Sadeghi investigated response of the railway track system to the artificially induced sleeper vibrations in order to obtain track dynamic coefficient [22]. However, this method is suitable for determination of sleeper support conditions.

The research conducted by Lazarević in 2014. proved the reliability of the measurement system for micro-tremor sampling presented in Figure 6 [3,4]. The micro-tremor contains the continuous ambient micro-vibrations that transfer from the surrounding soil to the railway structure. Therefore, this research implied analysis of sleeper response to the naturally induced vibrations.

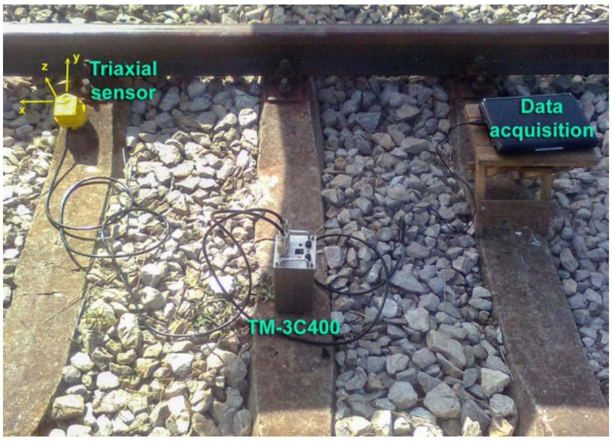

Fig.6. The measurement system for micro-tremor sampling [3,4]

The main advantages of the micro-tremor measurement system are: its portability, ease of set-up and speed of measurements, and it can be used on operational lines [3,4].

5. CONCLUSION

Accumulated traffic load leads to inevitable ballast bed degradation and track geometry deterioration.

Accordingly, it is necessary to define maintenance policy and strategy in order to ensure continuous condition monitoring, thus providing the basis for preparation and application of short term and long term plans of optimal maintenance.

Poorly supported sleepers can significantly reduce the service life of ballast bed, and at the same time negatively influence track geometry degradation. Therefore, these sleepers need to be examined to detect problems, and appropriate maintenance activities performed as early as possible. This approach ensures the possibility of reducing the overall maintenance costs.

This paper reviewed methods that can be used to determine sleeper support conditions. These methods are divided into continuous and manual, depending on the in-field application, and into direct and indirect, depending on the type of the obtained results.

Each method has its advantages and disadvantages related to the field application and reliability of the results. However, Infrastructure Manager has the responsibility to choose the optimal method by considering:

- level of investigation (network or section),
- reliability of the obtained results,
- time to set up and carry out the investigation,
- costs,
- transport to the field and need for the track closure.

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