53rd CONFERENCE ON EXPERIMENTAL STRESS ANALYSIS
Český Krumlov, Czech Republic, June 1–4, 2015

Investigation of Stress in the Railway Substructure in the Turnout

J. Smutny [1], L. Pazdera [2,*]

[1] *Brno University of Technology, Faculty of Civil Engineering, Department of Railway Structures and Construction, Veveri 95, Brno, Czech Republic*

[2] *Brno University of Technology, Faculty of Civil Engineering, Department of Physics, Veveri 95, Brno, Czech Republic*

[*] *pazdera.l@fce.vutbr.cz*

Abstract: The paper is focused on the stress measurement in the railway substructure in the turnout prototype designed for a high speed. The aim of the measurement and its evaluation was to compare the results obtained with theoretical presumptions. The methods of the measurement and its evaluation are described. The conclusions of the stress in the railway substructure included its relation with the train speed. It may also be stated that the quality elaboration of the measurement considerably contributed to modern means of the signal analysis.

Keywords: Stress; Railway; Substructure; Turnout; Wavelet.

1 Introduction

The railway substructure is one of the fundamental components of the railway line. By the railway substructure we understand the railway substructure body, the structures of the railway substructure, traffic areas and communications and small structures and the railway substructure equipment. From the viewpoint of the load transmission by railway carriages to the railway formation, the railway structure is divided into two basic components: the flat framework made up of rails and sleepers and the structure that consists of ballast bed, structure layers and formation. The upper surface of the roadbed is formed by the ballast bed. The construction of the railway substructure must be such to permanently secure the prescribed geometrical position and to secure the transmission of both the static and dynamic loads by railway carriages without a permanent deformation of the track bed [1,2].

It is evident that especially the construction layers of the railway substructure and the soil under the track bed are decisive for damping dynamic effects. The spreading of the dynamic effects in the railway bed is damped to a small extent only, most of the energy is transferred lower [3,4].

Even though the theoretical preconditions of spreading the stress in the construction of the track are known, it is necessary to support them by means of a practical measurement. This fact holds good especially when verifying new designs of the superstructure and finding out their effects on the subgrade. The follow text deals with the stress measurement and evaluation in the construction of the railway substructure under the prototype turnout for high speed. The design of the turnout offers a smoother run of railway carriages and a reduction of dynamic effects of a carriage on the rails and other structural layers of the railway bed.

It is worth noting that the presented sensors and analysis methods were used in the period 2004-2012 at selected joints and in other sections of the railway track in the research and analysis of dynamic effects.

2 Measurement Methodology

The subject of the measurement was the stress measurement in the construction of the railway substructure in the turnout No. 5 in the railway station of Vranovce (section of the Czech railway corridor linking Vienna, Prague and Berlin), type J60-1:12-500 (Fig. 1), provided with a movable frog. The rails are fixed to concrete sleepers by means of a flexible fastening of the Vossloh type. In the switch part of turnout there are two trough sleepers, in the common crossing there is one trough flange type sleeper [5].

To the measure of the normal stress, special pressure sensors inserted in the railway substructure during the construction operations were used. The sensors were placed in the turnout exchange part and under the movable frog.

At each observed point, two sensors were placed – the first one on the formation, the other one immediately under the ballast bed. The measurement utilised plate sensors of the series 3500 made by the firm GEOKON (Fig. 2) [6]. These sensors are filled with oil and the change of pressure is transferred to the outlet electric signal, the voltage is ranging from 0 to 5 V. The sensor diameter is 230 mm, the sensor thickness is 12 mm. Based on the preliminary analysis, the following sensors were chosen:

- for the formation within the range to 100 kPa,
- for the base of ballast 250 kPa.

The sensors were embedded into the construction during the performed reconstructions. The measurement ranges were determined based on the expected static stress acting in relevant depth of the railway substructure. The dynamic contribution was assumed to be maximally of the value of the static load, i.e. the value of the dynamic coefficient δ_{max} = 2.0. For the measurement, sensors of the stress range of the nearest higher value of the manufacturer production series were chosen.

Fig. 1: Turnout No. 5 in the railway station of Vranovice.

The train speed was monitored by means of two tensometric sensors placed on the bases of the rails [7]. The tensometric sensors were placed in the middle and in the frog parts of the turnout. The tensometric sensors formed on 18 mm long basis.

Two sections in the turnout were used for the measurement. A section in the switch part was chosen where the wheel passes from the bent stock rail to the straight switch blade. In the common crossing section, the sleeper under the common crossing point was chosen. The common crossing point occurs immediately on the trough sleeper in which it may be expected that the manner of the load transmission to the structure of the railway substructure differs from common concrete sleepers. This was the reason why the nearest adjacent concrete sleeper was chosen.

Fig. 2: Pressure sensor of series No. 3500 made by the firm Geokon.

Fig. 3: General view of the working place.

The measurement was preceded in two stages. The first stage was realised after the operating load of 1.910 mill. transported gross tons had been run through. This load was found out by a long-term measurement. The second stage of the measurement was carried out after the operating load of approx. 9 mill. transported gross tons had been run through. Altogether 50 records were made both in the first and second stages. The normal stress at the selected measuring points was measured for trains running at the speed from 70 to 160 km·h^{-1}.

3 Measurement Evaluation

Having analyzed the check measurement and the calculations, the following methods and parameters were used for the evaluation of the signals measured:

- time display of the course of normal stresses at particular measuring points, the evaluation of extreme stress values,
- descriptive statistics,
- estimates of mean values (t-test) and scattering (F-test), the tests were carried out at the significance level $\alpha = 5$ %,
- to determine the measure of interdependence of the highest stress values for the train passage, the correlation coefficients for particular groups of trains were calculated,
- the decomposition of the signals measured into the stress quasi-static and dynamic components was accomplished by a filter made on the principle of the discrete Wavelet transformation.

The geostatic stress for all sensors is in accordance with the conditions under which the sensors were placed. For the values of the highest stress ascertained during the train passage, the descriptive statistics were set up independently for either stage of the measurement. These results from the descriptive statistics presenting that the mean values of the highest values ascertained for the train passage through the common crossing, both for the subgrade and for the track bed are lower than for the sensor in the turnout change part. The ratio of the mean values is approximately 2:3. The stress under the common crossing point is lower compared with the values measured under the change part. The reasons are probably as follows:

- to determine the measure of interdependence of the highest stress values for the train passage, the correlation coefficients for particular groups of trains were calculated,
- the decomposition of the signals measured into the stress quasi-static and dynamic components was accomplished by a filter made on the principle of the discrete Wavelet transformation,
- the sleepers used in the common crossing are longer, the stress is distributed on a larger area.

The selected signals (covered all types of trains) were distributed into a quasi-static and dynamic components. The decomposition was carried out by a special filter working on the principle of the discrete Wavelet transformation.

The Discrete Wavelet Transform (DWT) is an orthogonal function which can be applied to a finite group of data. Functionally, it is very much like the Discrete Fourier Transform. Whereas the basis function of the Fourier transform is a sinusoid, the wavelet basis is a set of functions which are defined by a recursive difference equation [8, 9]

$$\phi(x) = \sum_{k=0}^{M-1} c_k \cdot \phi(2 \cdot x - k) \tag{1}$$

where the range of the summation is determined by the specified number of nonzero coefficients M. The number of nonzero coefficients is arbitrary, and will be referred to as the order of the wavelet. The value of the coefficients is, of course, not arbitrary, but is determined by constraints of orthogonality and normalization [10, 11] Eq. 1 is orthogonal to its translations; i.e. $\int \phi(x) \cdot \phi(x-k) \cdot dx = 0$. What is also desired is an equation which is orthogonal to its dilations, or scales, i.e. $\int \psi(x) \cdot \psi(2 \cdot x - k) \cdot dx = 0$. Such a function ψ does exist, and is given by next equation

$$\psi(x) = \sum_{k=0}^{M-1} (-1)^k \cdot c_k \cdot \phi(2 \cdot x + k - M + 1) \tag{2}$$

where $\phi(x)$ is a scale function $\psi(x)$ is a mother wavelet, k is the order of the wavelet, c_k are non-zero coefficients defining the mother wavelet, M is the number of non-zero coefficients c_k. A mother wavelet is subject to certain restrictions given by the below equations [12].

$$\sum_{k=0}^{M-1} c_k = 2 \tag{3}$$

$$\sum_{k=0}^{M-1} (-1)^k \cdot k^m \cdot c_k = 0 \quad \text{for} \;\; m = 0, 1, 2, ..., \frac{M}{2} - 1 \tag{4}$$

$$\sum_{k=0}^{M-1} c_k \cdot c_{k+2m} = 0 \quad \text{for} \;\; m = 1, 2, ..., \frac{M}{2} - 1 \tag{5}$$

$$\sum_{k=0}^{M-1} c_k^2 = 2 \tag{6}$$

Several efficient algorithms have been devised for discrete Wavelet transformation calculations of which Mallat's pyramid algorithm [13] is perhaps the most widely used. The algorithm operates on a finite set of N input data, where N is a power of two, this value will be referred to as the input block size. These data are passed through two convolution functions, each of which creates an output stream that is half the length of the original input. These convolution functions are filters, one half of the output is produced by the "low-pass" filter function, related to Eq. 1:

$$A_i = \frac{1}{2} \sum_{j=1}^{N} c_{2i-j+1} \cdot f_j \quad \text{for} \;\; i = 1, 2, ..., \frac{N}{2} \tag{7}$$

and the other half is produced by the "high-pass" filter function, related to Eq. 2:

$$D_i = \frac{1}{2} \sum_{j=1}^{N} (-1)^{j+1} \cdot c_{j+2-2i} \cdot f_j \quad \text{for} \;\; i = 1, 2, ..., \frac{N}{2} \tag{8}$$

where N is the input block size, c are the coefficients, f is the input function, and A and D are the output functions. In the case of the lattice filter, the low- and high-pass outputs are usually referred to as the odd and even outputs, respectively [14].

The wavelet filter was calibrated at standing, slow and fast moving test train set on the railway track in Cerhenice (Czech Republic).

Figs. 4, 5 and 6 shows the measured signals of three sensors. The upper graph of each figure represents the original record, the middle graph shows the stress quasi-static component and the lower graph the stress dynamic component computed by the Wavelet Transformation.

The dynamic increment for the subgrade is approximately 1.3 multiple of the quasi-static value, for the track bed it is as much as the 2.0 multiple. The comparison of the measurement for the first and the second stages of measurement revealed that in the common crossing the stress quasi-static component slightly decreased, and the dynamic component slightly increased. The observed changes are probably connected with the changes of bedding the sleepers on the ballast bed and with the repeated character of the load.

Then, correlation coefficients between the largest stress and the train speed for particular groups of trains and for all records in a given stage of the measurement were calculated. Only a statistically weak dependence of the stress extremes on the train speed was proved by means of the analysis. Thus, the general assumption that the mean value of the observed quantity is not almost dependent on the train speed was confirmed. However, the decisive deviation of the value, which in our case is the vertical stress, increases with the increase of the train speed.

4 Conclusion

The paper summarizes the experience obtained from the subject of the issue for years 2004-2012. In general, we may say that the ascertained values of the normal stress correspond with the theoretical assumptions. Although the stress was measured in dynamically exposed places of the turnout structure, it did not excessively

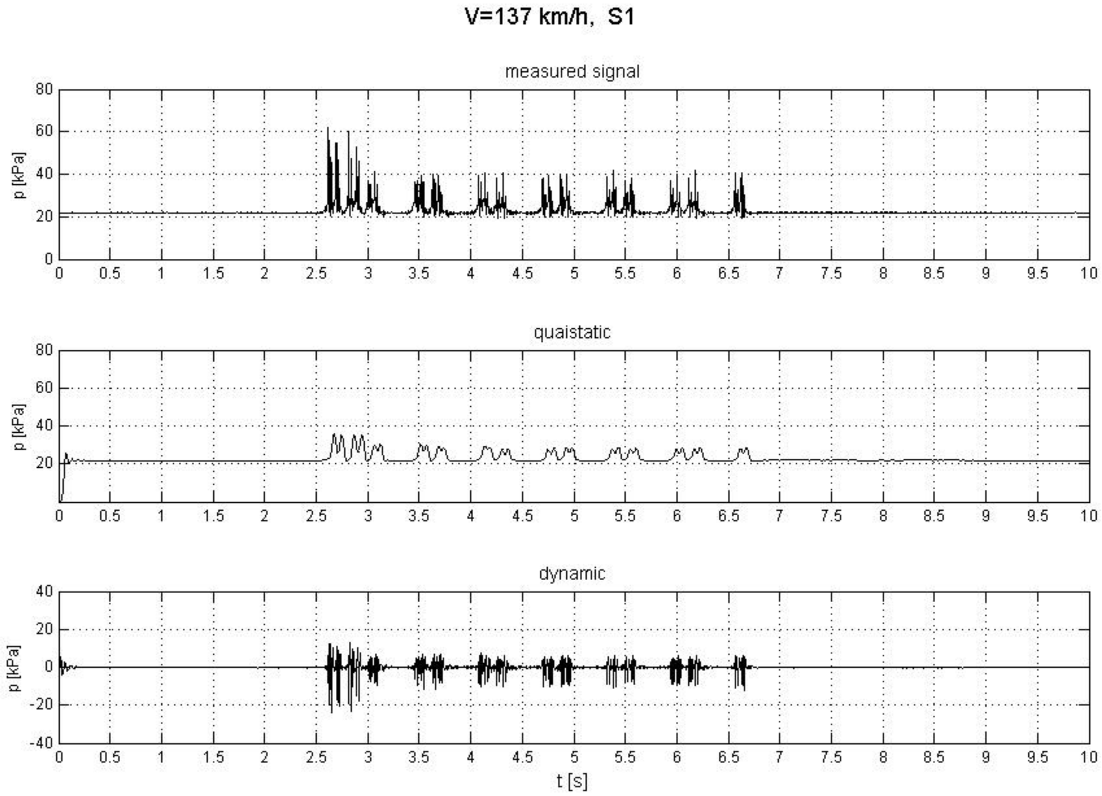

Fig. 4: The stress signals from sensor 1 for the passage of the set of carriages of the train and its distribution into the quasi-static and dynamic components.

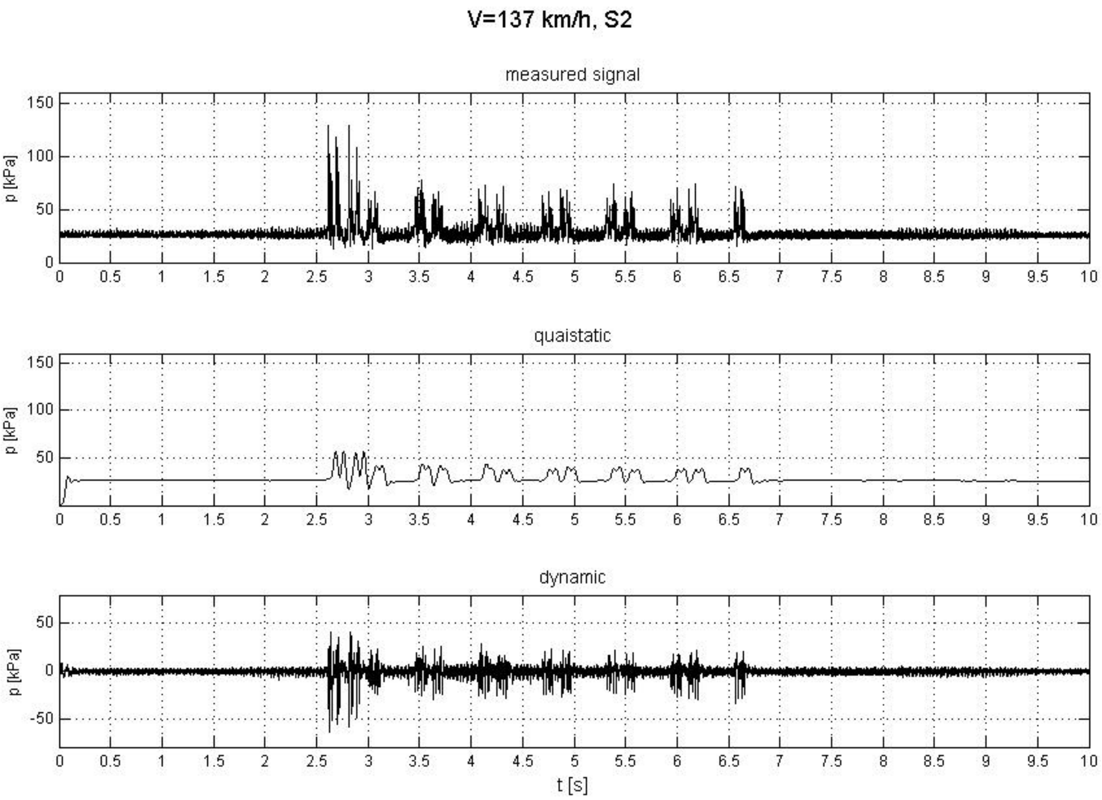

Fig. 5: The stress signals from sensor 2 for the passage of the set of carriages of the train and its distribution into the quasi-static and dynamic components.

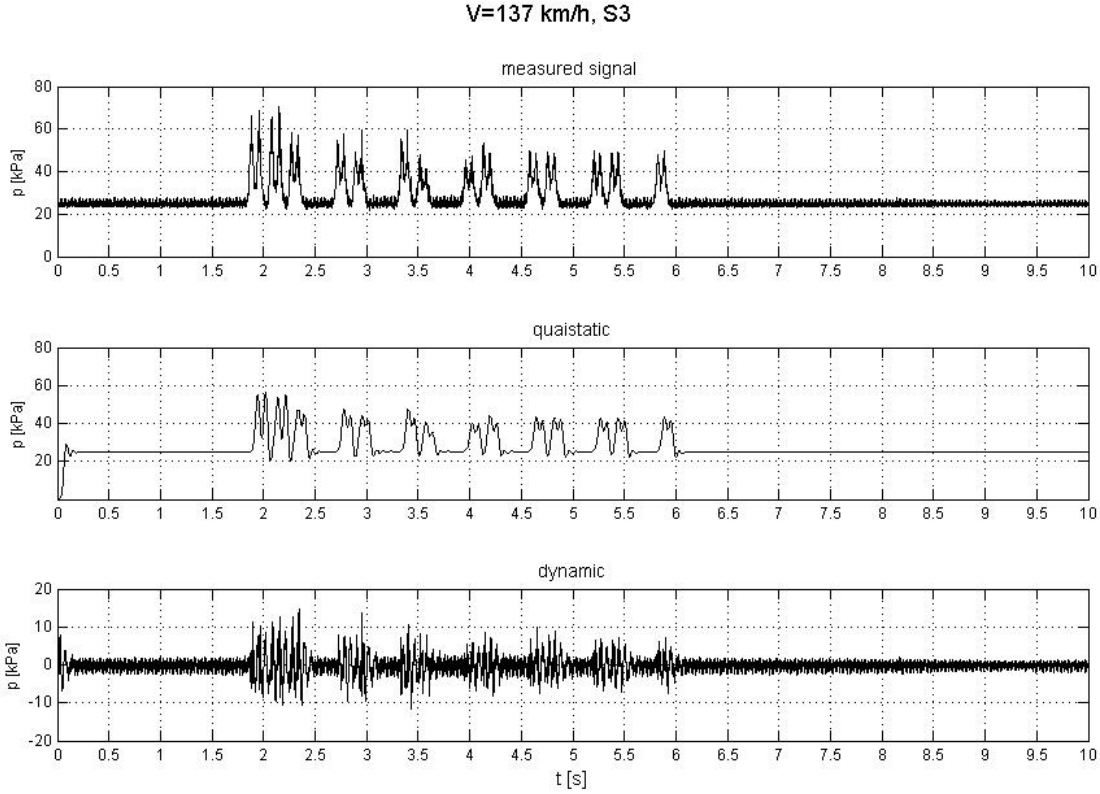

Fig. 6: The stress signals from sensor 3 for the passage of the set of carriages of the train and its distribution into the quasi-static and dynamic components.

exceed the values expected for a common rail. For this reason, it may be stated that the structural alterations in the turnout represent a clear contribution as regards the sleeper subgrade.

The measurement taken and the relevant analyses resulted in the following conclusions:

- descriptive statistics,
- estimates of mean values (t-test) and scattering (F-test), the tests were carried out at the significance level $\alpha = 5$ %,
- to determine the measure of interdependence of the highest stress values for the train passage, the correlation coefficients for particular groups of trains were calculated,
- the decomposition of the signals measured into the stress quasi-static and dynamic components was accomplished by a filter made on the principle of the discrete Wavelet transformation,
- the sleepers used in the common crossing are longer, the stress is distributed on a larger area,
- the load transmission is different for the sleeper in the common crossing and in the switch part, the previous analyses and measurements show that the largest stress due to the sleeper high bending rigidity occurs under the sleeper end and decreases towards the centre.

Acknowledgement

This article has been worked out under the projects:

No. LO1408 "AdMaS UP - Advanced Materials, Structures and Technologies", supported by Ministry of Education, Youth and Sports under the "National Sustainability Programme I"

No. FAST-S-15-2806 Analysis of the Dynamic Response of the Structure of the Railway Line supported by Brno University of Technology

No. TA01031297 - Improving the Quality of the Track in Switches Using More Flexible supported by Technology Agency of the Czech Republic.

References

[1] Kucharova D., Melcer, J. Building research journal, 50 (2002) 99-111.

[2] Indraratna B., Ionescu D., Christie H. D., Journal of Geotechnical and Geoenvirnomental Engineering, 124(5) (1998) 439–449.

[3] Brough M. J., Ghataora G., Stirling A. B., Madelin K. B., Rogers C. D. F., Chapman D. N. Proc. of the ICE - Transport, 159(2) (2006) 83–92.

[4] Mcdowell G. R., Lim W. L., Collop A. C., Armitage R., Thom N. H., Proc. of the ICE - Transport, 15(2) (2005) 89–95.

[5] Chen R., Wang P., Wei XK, Advanced Materials and Computer Science, PTS 1-3, Book Series: Key Engineering Materials, 474-476 (1-3) (2011) 1599-1604.

[6] Gao L., Qu C., Qiao SL., Cai XP., Liu W., Science China-Technological Sciences, 56 (2) (2013) 499-508.

[7] Smutny, J., NDT & E International - Independent Nondestructive Testing and Evaluation, 37(2) (2004) 119-129.

[8] Strang, G., SIAM Review, 31(4) (1989) 614-627.

[9] Smutny J., Pazdera L., InSight, The Journal of The British Institute of Non-Destructive Testing, 46(10) (2004) 612-615.

[10] Topolar, L, Pazdera, L; Bilek, V; Dedeckova, L, Proceedings of the 50th Annual Conference on Experimental Stress Analysis, (2012) 477-484.

[11] Mallat, S. A, IEEE Trans. Pattern Analysis and Machine Intelligence, 11 (1989) 674-693.

[12] Ahmad SS; Mandal NK; Chattopadhyay G; Powell J, Proceedings of the Institution of Mechanical Engineers Part F-Journal of Rail and Rapid Transit, 227(5 SI) (2013) 493-516.

[13] Pazdera, L, Topolar, L., Smutny, J, Proc. of the 52nd International Conference on Experimental Stress Analysis, (2014) 203-206.

[14] Smutny, J, Pazdera, L, Akustika, 21(1) (2014) 40-47.