Technical condition diagnosing of the cableway supports' foundations

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Diagnostika fundamentovania nosnýc h podpor lanových dráh

The paper presents a test subject, which is a set of cableway support towers, and issues related to its diagnostics. The paper's essential part of the paper concerns proposed method for evaluating technical condition of joints between tower's supporting structure and its foundation, which is based on vibrations' acceleration of joints' elements tests results analysis. The final part presents analysis results for one of tested supports, obtained before and after an overhaul.

***Key words**: cableway support, coherence function, diagnostic, resonant frequency*

Introduction

During a long-term cableway's operation, there is a requirement for periodic evaluation of support towers foundations. One ending of supports' steel construction is mounted to a foundation, while there is a dynamic load of a cable acting on the second one, through a battery of cableway trolleys. Long-term operation with changing loads, and highly diversified atmospheric conditions, can lead to defects in concrete foundation's structure, atmospheric corrosion of steel construction, or loosening of anchors. Periodic tests are aimed at detecting this kind of defects, not to allow hazardous operation. Lack of access to examined elements, and difficulties in visual evaluation of joints between support tower and its foundation is a serious problem during defects detection. Tests described in this paper concern a complex of three sections of cableway, with 62 support towers, which is being exploited for 40 years in The Culture and Recreation Park in Silesia. Further cableway's operation required, among others, an evaluation of supports foundations' technical condition. Visual evaluation indicated a large corrosive wear of support towers, and defects in external layer of concrete foundations. This could lead to weakening of joints between these elements, and thereby cause a failure. The cableway, which was subjected to tests, is a lowland, recreational and scenical object. Maximum altitude difference during the whole route amounts to 42 m. The cableway was repaired several times in the past, and it undergoes a technical survey once a year. Repair works were conducted on concrete elements of supports' foundations, among others.

Fig. 1. A view of tested cableway's support tower.

This caused a heterogeneity in concrete structure, with individual layers varying in quality. A photography of one of tested support towers is shown in Fig. 1.

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Diagnostic tests

Fig. 2 shows a place of mounting support to foundation with an anchor. It can be seen, that elements of steel construction are highly corroded.

Fig. 2. A joint of support structure and foundation.

In attempt to select defected supports for repairs, a method based on measurements of theirs vibrations' acceleration was proposed. Acceleration of vibrations for each foundation and support was measured simultaneously, at maximum load and rated velocity of the cableway. Cableway's chairs were loaded with sandbags in order to reach maximal load capacity. A scheme of measurement system along with marked sensors (1 and 2) is presented in Fig. 3.

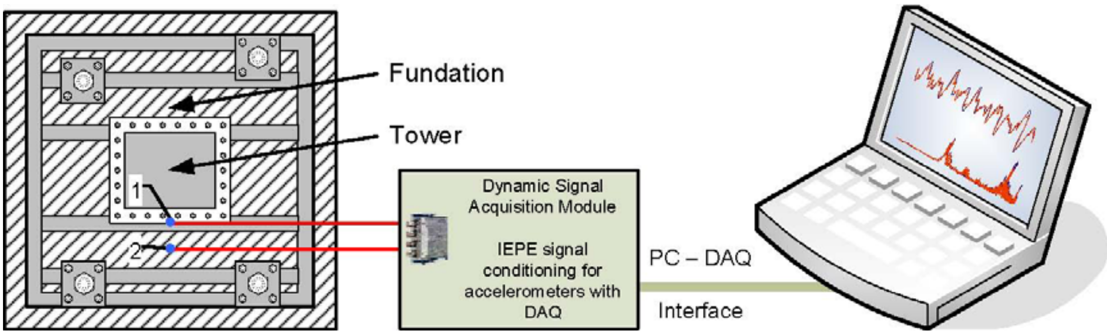


Fig. 3. Measurement diagram.

Piezoelectric acceleration transducers (made by PCB) were used for measurements. Basic parameters of implemented transducers are:

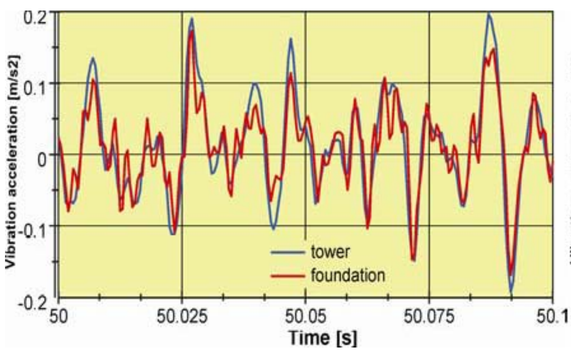
• Sensitivity (± 5 %)	102 mV/(m/s²)
• Measurement Range	± 49 m/s² pk
• Frequency Range (± 3 dB)	0.2 to 6000 Hz
• Resonant Frequency	≥ 10 kHz
• Broadband Resolution (1 to 10,000 Hz)	0.0001 m/s² RMS
• Non-Linearity	≤ 1 %
• Excitation Voltage	18 to 30 VDC
• Constant Current Excitation	2 to 20 mA
• Output Impedance	<250 ohm
• Output Bias Voltage	8 to 12 VDC
• Discharge Time Constant	1 to 3 sec
• Settling Time	<15 sec
• Sensing Element	Ceramic
• Sensing Geometry	Shear
• Size (Hex x Height)	30.2 mm x 55.6 mm
• Weight	210 gm

Adhesive mount for the sensor has been used DAQ is a signal acquisition module for conducting high-accuracy measurements from integrated electronic piezoelectric (IEPE) sensors. 24-bit resolution ADCs with 102 dB of dynamic range delivers and incorporates IEPE signal conditioning for accelerometers. The input channels simultaneously digitize input signals at rates from 2 to 50 kS/s (kilo sample per second). Measurement computer was used for an introductory analysis and an acquisition of measured signals. During the tests vibration' accelerations were measured and recorded in one minute time intervals.

A way of fixing vibration sensors to tested elements is shown in Fig. 4.

Fig. 4. A layout of sensors on tested elements: a) detailed view, b) overall view.

In correct case, that is when the joint between the foundation and the support is rigid, time functions of vibrations' acceleration should be coherent, regarding amplitude and phase. If backlashes in their joints occur, amplitude of support vibration's acceleration is higher than amplitude of foundation vibration's acceleration. Moreover, there is no coherence in phases of accelerations. The fragment of time functions of support and foundation vibrations' acceleration for two chosen constructions (no. II.13 and III.5) was shown in Fig. 5 and 6.



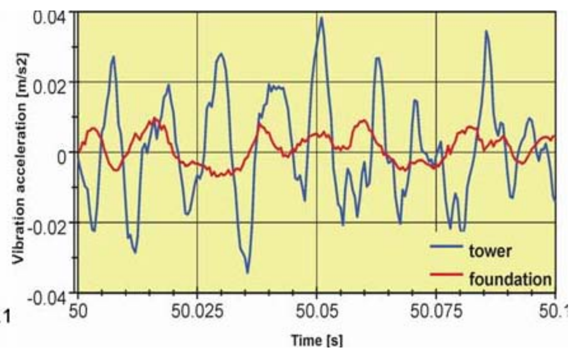


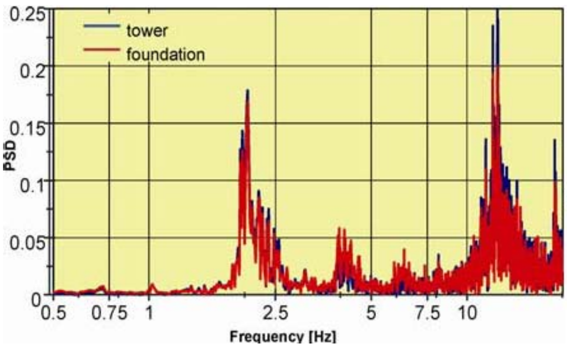
Fig. 5. Time functions of vibrations' acceleration for Fig. 6. Time functions of vibrations' acceleration for construction no. II.13 construction no. III.5.

Fig. 5 shows relatively high consistency of support and foundation vibrations' acceleration. It can be concluded then, that foundation II.13 does not need repair (remontu). However, an analysis of time functions which fragment is presented in Fig. 6 enables the conclusion, that the joint between foundation and support no. III.5 is damaged.

Weakening of the tested joint can also be observed on power spectrum density (PSD) characteristic of measured signals'. Those characteristics are presented in Fig. 7 and 8 consequently for constructions II.13 and III.5. Too high discrepancy between tower and foundation PSD characteristic can indicate an occurrence of backlashes in this joint.

Characteristics of a power spectrum density allows an evaluation of joint's technical condition in specified frequency bands as well. Characteristics presented above do not provide quantitative evaluation, which can be obtained by implementation of coherence function. Coherence function between output signal *y* and input signal *u* is defined in equation (1):

$$\zeta^2(\omega) = \frac{S_{uy}(j\omega).S_{yu}(j\omega)}{S_{uu}(\omega).S_{yy}(\omega)}$$



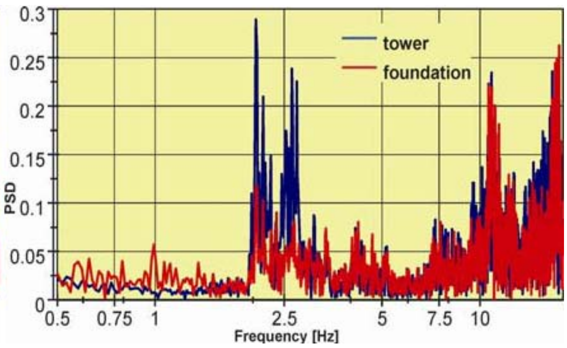


Fig. 7. Power spectrum density function for vibration's

Fig. 8. Power spectrum density function for vibration's acceleration for construction no. II.13 acceleration for construction no. III.5.

This function is a frequency coefficient of a correlation between signals *u* and *y*. It's values are in range of [0,1]. If coherence function's value amounts to 0, signals *u* and *y* are independent. If value equals 1, output signal *y* is a linear combination of input signal *u*. For coherence function's values greater then 0, but less then 1, at least one of three cases occurs:

- measurement results have errors resulting from disturbances,
- a system connecting signals *u* and *y* is non-linear,
- output signal *y* is a result of influence of input signal *u*, and others, not considered input signals.

Evaluation of coherence function is obtained basing on determined estimates of power spectrum densities, and reciprocal spectrum densities (Bielińska, 1997; Bendat, 1976). Coherence functions for support and foundation vibrations acceleration's signals for constructions no. II.13 and III.5 are presented in Fig. 9.

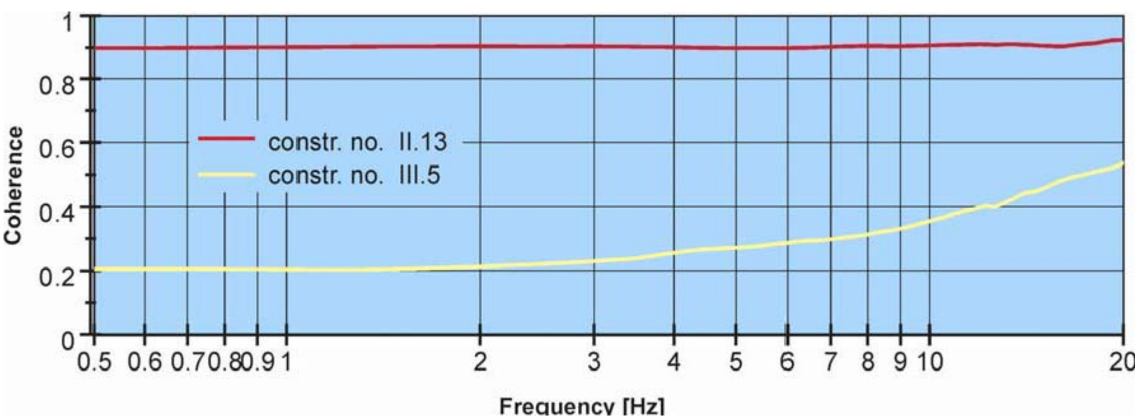


Fig. 9. Analyzed constructions coherence function for foundation vibrations in respect to support vibrations.

The most important frequency band, for the cableway's support tower, includes it's natural frequency, which is an individual characteristic for each one of supports. Therefore, a value of coherence function for a natural frequency was chosen as an evaluation criterion. After an analysis of all support towers' test results, $\zeta = 0{,}75$ was established as a boundary value. For values below this one, it was acknowledged, that tested support tower requires an overhaul to make joint between it's construction and foundation more rigid. The overhaul was primarily a strengthening of supports' construction, and installation of additional strengthening anchors. Results of the conducted overhaul were tested by a new evaluation of foundation supports' technical condition.

After the overhaul specified basing on construction measurements, diagnostic tests were conducted again.

The fragment of time function of support and foundation vibrations' acceleration, after the cableway's overhaul was shown in Fig. 10. A high consistency between support and foundation vibrations' acceleration can be observed. From the presented fragment of time function it can be seen, that amplitudes of support and foundation vibrations' acceleration have similar values.

In order to check consistency of those amplitudes in full frequency range, a power spectrum density (PSD) characteristic, shown in Fig. 11, was created.

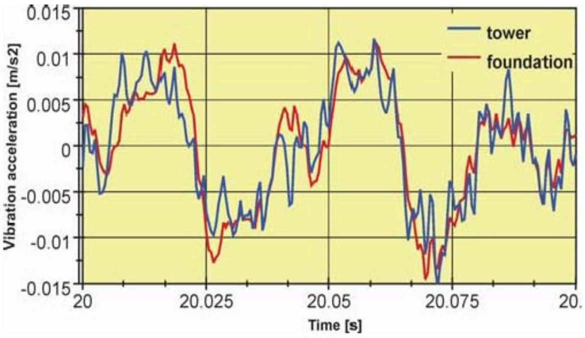


Fig. 10. Time functions of vibrations' acceleration for construction no. III.5 after the overhaul.

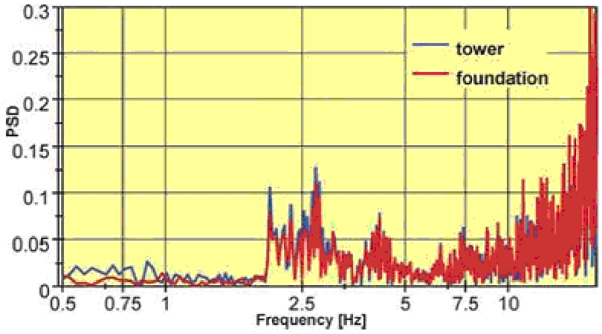


Fig. 11. Power spectrum densitz function for vibration's acceleration for construction no. III. 5 after the overhaul.

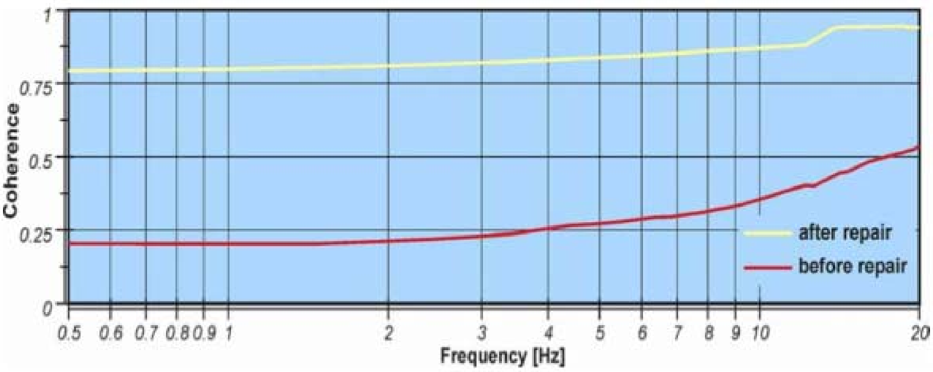


Fig. 12. Coherence function for foundation vibrations in respect to support vibrations before and after the overhaul.

It confirms an improvement of rigidity of the joint between foundation and support in tested frequency range. Improvement degree was evaluated by comparing coherence functions before and after the overhaul of the support no. III.5. Coherence functions for support and foundation vibrations acceleration's signals, before and after the overhaul, are presented in Fig. 12.

Increased value of the coherence coefficient for the free vibrations frequency from 0.21 to 0.81 can be observed. It is a significant improvement in comparison to the value from before the overhaul.

Conclusions

Proposed method for diagnosing cableway's support towers, using coherence function in resonant frequencies band, allows fast, inexpensive, non-destructive, and efficient evaluation of supports steel constructions and foundations joints' technical condition. This method was verified in practice, and received a positive evaluation from Transportation Technical Supervision (office supervising means of transport in Poland).

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