Impact of the vibrations on the environment caused by passages of trains at variable speed

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Abstract. The paper deals with negative environmental impact caused by the passages of different kinds of trains at variable speed. The study is based on the measurement results which took place in Poland in 2013 on the railway line no. 4. The effect of the traction unit – Pendolino (EMU 250) on the vibration climate was analysed. The impact of passages of new trains was compared to currently operated rolling stock. The speed of trains was varying between 40 and 250 km/h. Vibration measurements were conducted by stuff of an accredited Laboratory of Structural Mechanics at Cracow University of Technology (Accreditation No. AB 826). The influence of the indicated vibrations due to passages of the trains on the building in the neighbourhood of the line was investigated. The vibration assessment was done for horizontal components of vibrations according to Polish standard code. Assessment of environmental impact was presented by indicator of perceptibility of vibration through construction (WODB), which refers to the Scales of Dynamic Influences (SDI scales). The limits specified by standards in any of the passages have not been exceeded. The change of speed or rolling stock resulted in a change in the characteristic of the vibration spectrum.

1 Introduction

Although it is not commonly associated with environmental pollution, vibration from roads and railways has a negative impact on the surrounding. Numerous standards and laws (both Polish [1,2] and foreign [3-5]) govern issue of vibration emission. Using world literature in the field of mechanical vibration, among others [6-8], it can be stated that the issue of vibration excited by trains is an important issue of the modern world. The problem is increasing in proportion to the increase in train speed and the creation of new high-speed line. As mentioned in [9], ground vibration limits are exceeded in 44% of assessment (worldwide investigation). Review of over 2300 technical railway vibration papers and holistic vibration prediction (from track to nearby building) we can found in [10].

2 Background information

In November 2013, before the authorization for the use of newly purchased trains, the Polish network line manager organized test during the passage of Pendolino (EMU 250) at speed varying between 40 and 293 km/h. This opportunity was taken to perform the vibration measurement e.g. on the track, ground and building. Electric Multiple Unit was crossing section Psary - Góra Włodowska (approximately 36 km) located within the railway line No. 4 (CMK). The train was following track "A" with closed two tracks for other vehicles during three weekends. During weekdays analogical studies were done for rolling stocks running the CMK section. Similar studies were performed and discussed in paper [11].

The paper presents selected results of measurements of building vibration (horizontal components of vibration: x – perpendicular and y – parallel to the axis of the track), in one of the three measuring polygons. The assessed building was located within 50 m of the track. Passages of the EMU 250, the InterCity and the InterRegio trains induced vibrations. The data from trains runs with a speed of 40 and 250 km/h is a base of comparison.

The accredited Laboratory of Structural Mechanics at Cracow University of Technology (Accreditation No. AB 826) performed in situ measurements.

Analyses were performed based on the knowledge and experience of the researchers and are also available in references [12-17].

3 Measuring polygon and equipment

Vibration measurements were performed with piezoelectric accelerometers' PCB Piezotronics and analyzer SCADAS Mobile's LMS International. The relative standard uncertainty of the maximum signal acceleration must not exceed ± 11.61%, which is the sum of the deviations of nominal sensors and amplifier distortion by the digital recorder and the accuracy and linearity of the amplifier. In the test, schematic arrangement of sensors is shown in Fig. 1. Tested

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residential building was 50 m from the track A. The tracks and structures were separated by shallow drainage ditch.

Two sensors recording the horizontal vibrations: perpendicular (labelled as P-01x) and parallel (labelled as P-02y) to the x and y axis respectively. Accelerometers were fixed on the building foundation, at ground level. Mounting the sensor on the basis was carried out according to the method featured in [18].

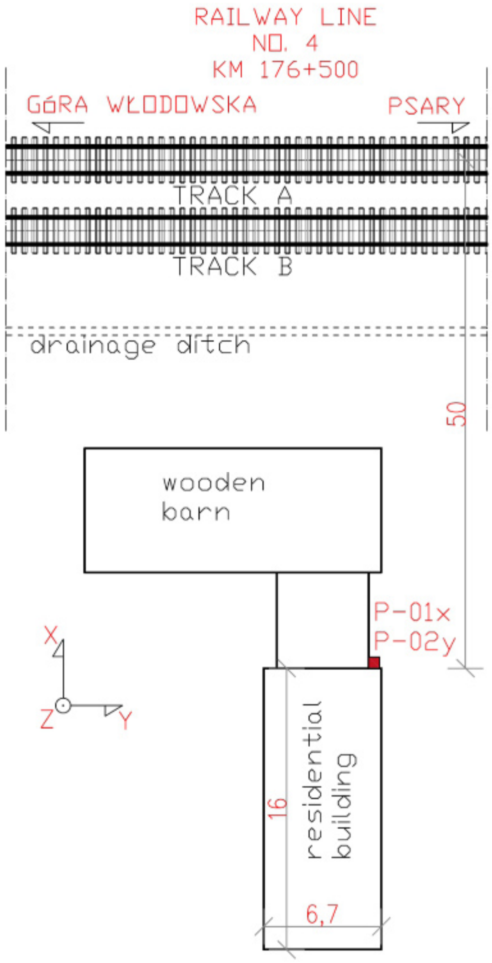

Figure 1. Schematic arrangement of sensors in the measuring profile

4 Analyses

4.1 Analysis of acceleration records

There were analysed all measured time histories and frequency contents of the horizontal accelerations of the residential building. The exemplary time history of the building acceleration recorded at the ground level during the passage of Pendolino with speed 250 km/h is presented in the Fig. 2.

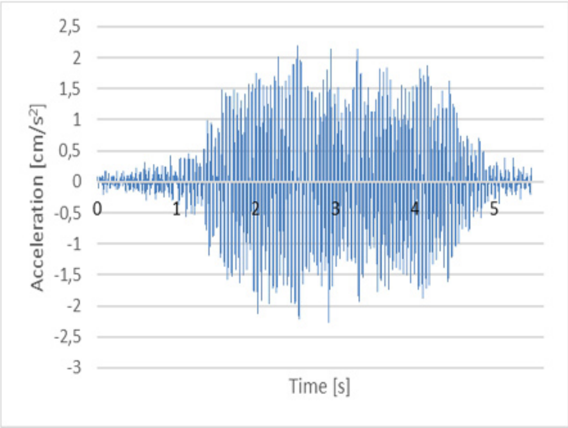

Figure 2. Measured time history of horizontal acceleration of the building at ground level during passage of Pendolino with a speed v=250 km/h

Fig. 3 shows the maximum values obtained from the time history of the acceleration of horizontal components P-01x of vibrations caused by passages of the Pendolino and other trains with speed 40-250 km/h. Similarly, Fig. 4 presents the maximum values of P-02y sensor.

The growth curves of maximum values of vibration acceleration versus velocity of the EMU 250 were fitted and shown in Figures 3 and 4. For each set of data there is the exponential function given. It describes the dependence of the maximum acceleration of train speed. The coefficients of determination R^2 for both functions is above 0.8. The maximum values of vibration acceleration showed significantly difference depending on the type of train (Pendolino or InterRegio). The extremal values of other trains are often higher than Pendolino's once.

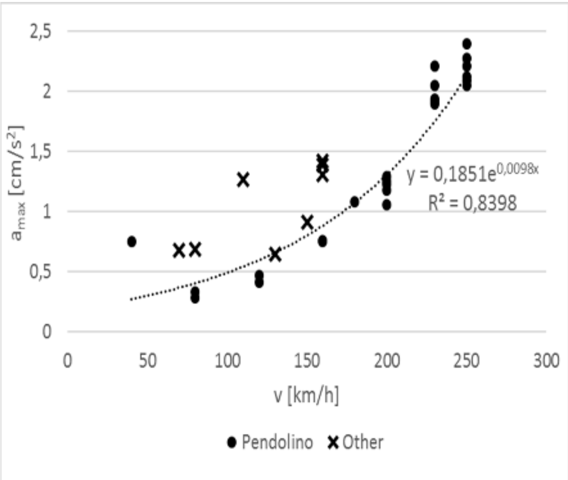

Figure 3. The maximum value of the horizontal component x of vibrations from the recorded accelerations caused by trains at variable speed

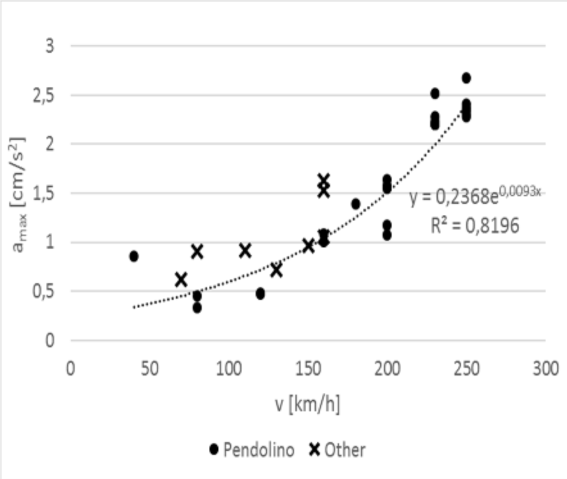

Figure 4. The maximum value of the horizontal component y of vibrations from the recorded accelerations caused by trains at variable speed

4.2 Vibration spectrum analysis – SDI scale

Assessment of vibration harmfulness for the building was done for the horizontal components of vibrations (X and Y) according to Polish standard [19]. The investigated structure was classified to scale SDI-II. The measured time histories of the horizontal acceleration were analysed using one-third octave band frequency filters and distributed in one-third octave bands of the mid-band frequency from 1 to 100 Hz. For example, Fig. 5 summarize the results of the horizontal vibration (sensor P-01x) recorded from Pendolino passages at speeds of v = 160 km/h (the blue columns). The obtained results are compared to the Scales of Dynamic Influences (SDI scales) (the red line). The maximum accelerations up to 6,3 Hz are smaller than for higher frequencies. All acceleration values in 1/3 octave bands are located in I zone of the SDI scale (below red line). It means that vibrations are not harmful for the whole building.

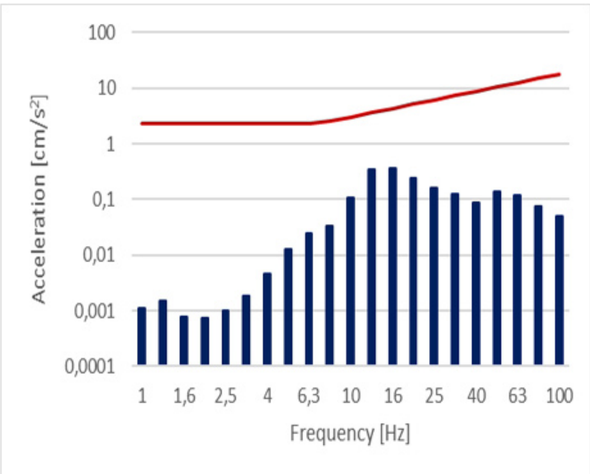

Figure 5. Vibration spectrum in one-third octave frequency bands with SDI scale – the measuring point P-01x – Pendolino trains – track A – speed trains v = 160 km/h

4.3 Vibration spectrum analysis – WODB

Assessment of environmental impact was presented using indicator of perceptibility of vibration through construction (WODB). In our case, indicator WODB is the largest value of the maximum values of the ratio of the vibration acceleration parameters in one-third octave bands to the acceleration corresponding to the lower limit consideration of dynamic influence on buildings due to the SDI scales in the same frequency band. The indicator is expressed as two numbers: dimensionless, designated in the manner mentioned above and middle frequency of one-third octave band in which the WODB is determined. The indicator was established for each passage. The usefulness of this ratio is fact, that the final result becomes independent of the frequency band. The WODB indicator shows directly how many times the lower limit consideration of dynamic influence on buildings has been exceeded [13].

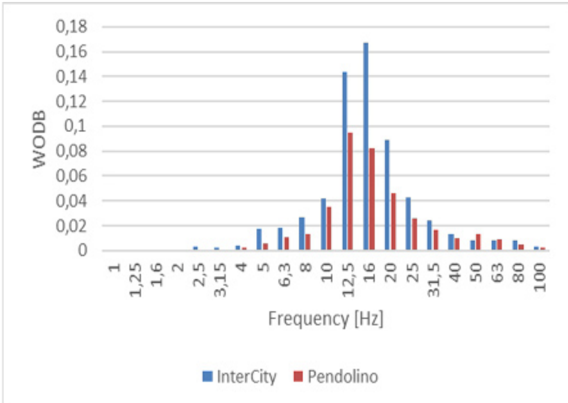

Figure 6. WODB spectrum in one-third octave frequency bands – the measuring point P-01x – Intercity and Pendolino trains – track A – speed trains v = 160 km/h

It was compared two types of rolling stocks: Intercity and Pendolino at speed 160 km/h (Fig. 6. for sensor P-01x and Fig. 7 for sensor P-02y). Both trains excite the greatest values of acceleration in the middle bands (12,5 – 20 Hz), but the values obtained by EMU 250 are lower especially in mentioned bands for horizontal vibration perpendicular to the axis of the track. The vibration parallel to the axis of the track is not as unambiguous. The differences between the values are smaller. The dominant bands extended between 10 – 20 Hz. For the frequency 12,5 Hz the EMU 250 train gets higher indicator. Nevertheless, this proves that using the new trains reduce negative impact of the vibration on the environment.

Fig. 8 and 9 present the impact of vibration on building depends on track which the train follow by. The analysis has been made for the Intercity train at speed v=160 km/h. Despite of the fact that the track B is closer the building, the results are not obvious. The records from P-01x and P-02y sensors have higher values of acceleration parameters for frequencies up to 12,5 Hz for track A.

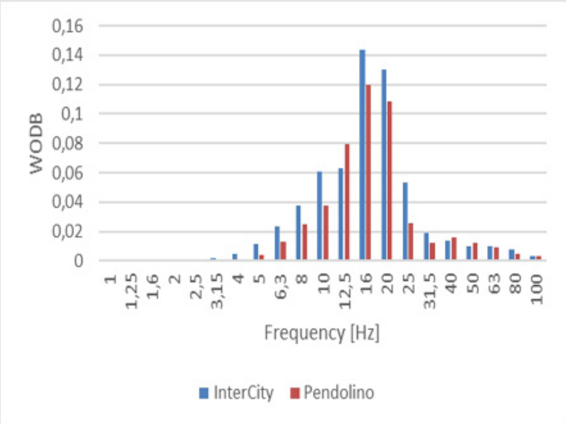

Figure 7. WODB spectrum in one-third octave frequency bands – the measuring point P-02y – Intercity and Pendolino trains – track A – speed trains v = 160 km/h

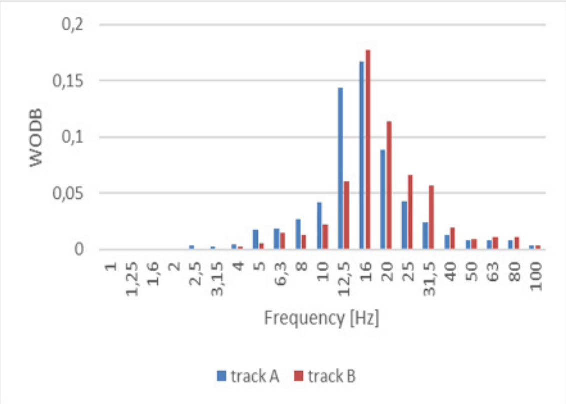

Figure 8. WODB spectrum in one-third octave frequency bands – the measuring point P-01x – Intercity trains – track A – speed trains v = 160 km/h – track A and B

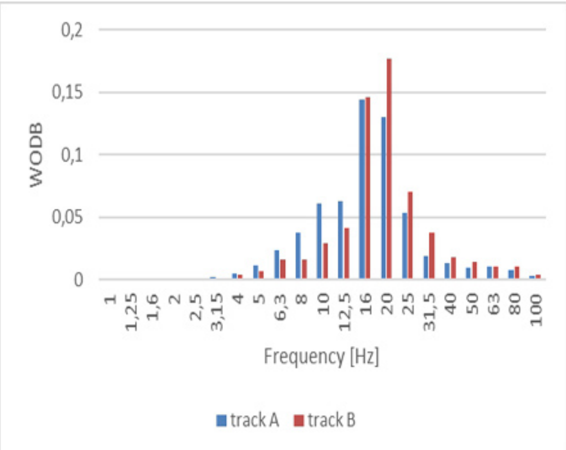

Figure 9. WODB spectrum in one-third octave frequency bands – the measuring point P-02y – Intercity trains – track A – speed trains v = 160 km/h – track A and B

To compare the vibrations perpendicular and parallel to the track axis Fig. 10 presents obtained maximum values of the coefficient WODB from all passage of Pendolino train for accelerometer P-01x and P-02y. The biggest difference reveals in the band 16 Hz, in which vibrations parallel to the axis have stronger influence on building. On the other side, it was compared similarly vibration excited by Intercity train at speed 160 km/h. The received results are less similar. The parameters of component y of vibrations are even two times higher than for component x for the frequency band 12,5 Hz. For frequency band 20 Hz, sensor P-02y measures higher acceleration.

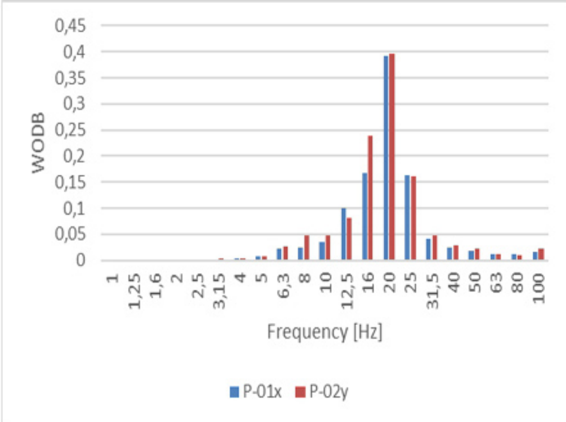

Figure 10. WODB spectrum in one-third octave frequency bands – the measuring point P-01x and P-02y – Pendolino – maximum values

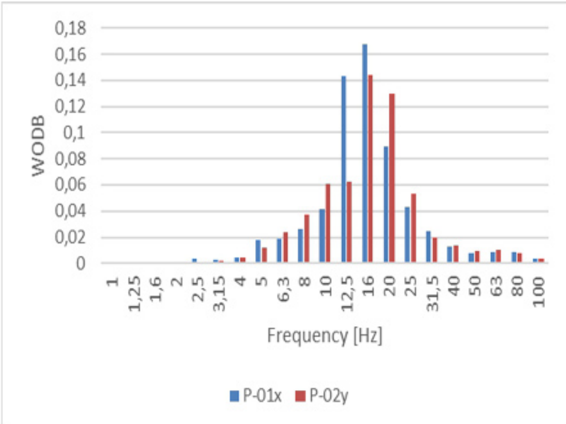

Figure 11. WODB spectrum in one-third octave frequency bands – the measuring point P-01x and P-02y – Intercity train – speed 160 km/h

Finally, passages of Pendolino have been divided into two categories: the passage with speed up to and above 160 km/h. For each of categories it has been choose the worst values of the coefficient WODB. The results obtained for P-01x and P-02y sensors have been compared and presented in Fig. 12 and Fig. 13, respectively. The diagrams show that not all frequencies increase depending on the growth of speed of the train. The large increase in frequency bands is noticed for the values in the bands 16-25 Hz. Other frequencies do not present such huge differences. Even higher speed refers to slightly smaller value of coefficient WODB, e.g. for 10 Hz band. For this reason, if we want to increase the velocity of train, we should focus on reducing the vibration in appropriate frequency bands rather than the entire range.

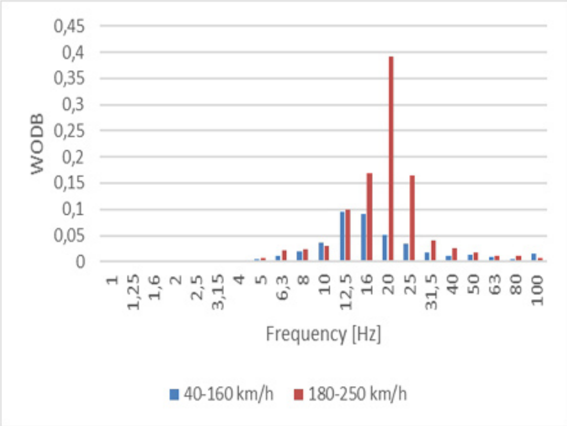

Figure 12. WODB spectrum in one-third octave frequency bands – the measuring point P-01x – Pendolino trains – the maximum values for speed trains v =40-160 km/h and v=180-250 km/h

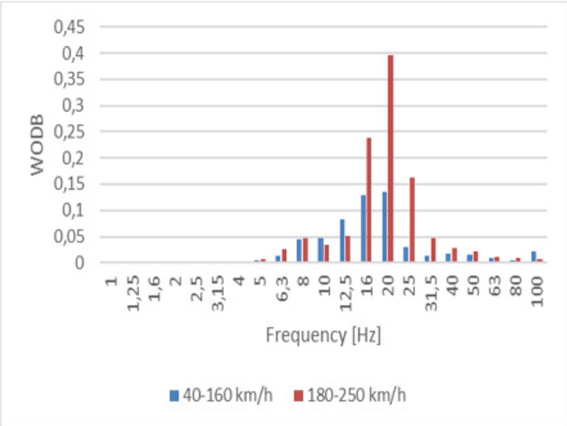

Figure 13. WODB spectrum in one-third octave frequency bands – the measuring point P-02y – Pendolino trains – the maximum values for speed trains v =40-160 km/h and v=180-250 km/h

5 Conclusions

This paper analysed negative environmental impact caused by the passages of trains. The following conclusions were made:

Train vibration is an area that affects environmental condition. Taking into account information from literature it is a global concern. It also applies to well-developed countries, where the railway infrastructure is advanced with the use of new technologies with the European standards. For this reason, transport has a great role in shaping the quality of the environment.

Assessment of environmental impact was presented by indicator of perceptibility of vibration through construction (WODB), which refers to the Scales of Dynamic Influences (SDI scales). The limits specified by standards [19] in any of the passages have not been exceeded. The change of speed or rolling stock resulted in a change in the characteristic of the vibration spectrum.

The limits specified by standards in any of the passages have not been exceeded on examined building. However replacement of old rolling stock trains by the new trains will reduce negative impact of the vibration on the environment.

Propagation of free-field vibrations in ground with their effect on the structural response of buildings near railway lines are complex phenomenon. Therefore it is difficult to assess the impact of vibration on buildings without in situ measurements. E.g. as proven above a train moving on a track further away from the building does not necessarily reach lower values of acceleration for each frequency band.

If we want to develop a network lines and increase the velocity of train to replace a part of road transport (because of air pollution), we should not forget about vibration pollution. In conclusion we must adjust rail system to be safe for all aspects of environment.

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