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To cite this article: B Kouch and T Tatara 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **214** 012100

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The environmental impact of the railways operations – the dependence of speed on the level of vibration emission

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Abstract. Railway transport plays a significant role in shaping the quality of the environment. Vibration from railways is a big concern for engineers. Because of its negative impact on the surrounding area, it is also an environmental problem. The paper deals with the dependence of speed on the level of vibration emission. It is based on the experimental study, which was done during the passage of the Pendolino train (EMU 250). Accredited Laboratory of Structural Mechanics at Cracow University of Technology has performed in situ measurements. Speed of the train was varying between 80 and 250 km/h. The evaluated construction was located at a distance of approximately 50 m from the railroad. Indicators of the perceptibility of vibration through constructions (WODB) were used to assess the impact of vibrations on the building. The innovation of this publication is the application of multi-criteria decision analysis methods for assessing the impact of vibration. The ELECTRE (Elimination and Choice Expressing Reality) methods to evaluate the increase in vibration emission depending on the speed for each frequency band are used. The limits specified by Polish standards in any of the passages have not been exceeded. As proven in the paper, a train speed increase does not uniformly make the vibration higher in each frequency band.

1. Introduction

The issue of vibration emission is governed by several standards and laws (inter alia [1-3]). With the attention paid to this subject in international literature [4-7], it is clear that the vibration induced by human activity is an important consideration throughout the modern world. It is well known that vibration induced by trains has a negative impact on the nearby area [8-11]. The increases in train speed and the creation of new high-speed lines increase the size of this problem.

The aim of this paper is to implement an application of Multi-Criteria Decision Analysis (MCDA) method ELECTRE I to assess the impact of train speed to the perceptibility of vibration through constructions. ELECTRE, which is a family of methods, is widely known and used in scientific work [12-13]. Nevertheless, the value of this work is the combination of WODB (indicators of the perceptibility of vibration through constructions) with the ELECTRE I method (Elimination and Choice Expressing Reality).

2. Background and measuring polygon

Before the authorisation for the use of the Pendolino trains (Electric Multiple Unit - EMUs 250), homologation and velocity tests were conducted in Poland. The new train was tested whilst crossing the Psary – Góra Włodowska section (a length of approximately 36 km) located within railway line No.



4. EMU 250 was running at predetermined speeds. Information about some of the studies can be found in the literature [14-16].

To perform measurement, a PCB Piezotronics piezoelectric accelerometer and a SCADAS Mobile LMS International analyser were used. Accelerometers were fixed on the building foundation. The investigated residential building was 50m from track A (where Pendolino were tested). The surveyed construction was a typical residential masonry building.

The paper presents selected results of measurements of building vibration induced by train at speed varying between 80 and 250 km/h. The station measured two mutually orthogonal horizontal components x and y of vibration accelerations labelled P-01 x and P-02 y , respectively. Fig. 1. shows the measuring polygon and the schematic arrangement of the sensors.

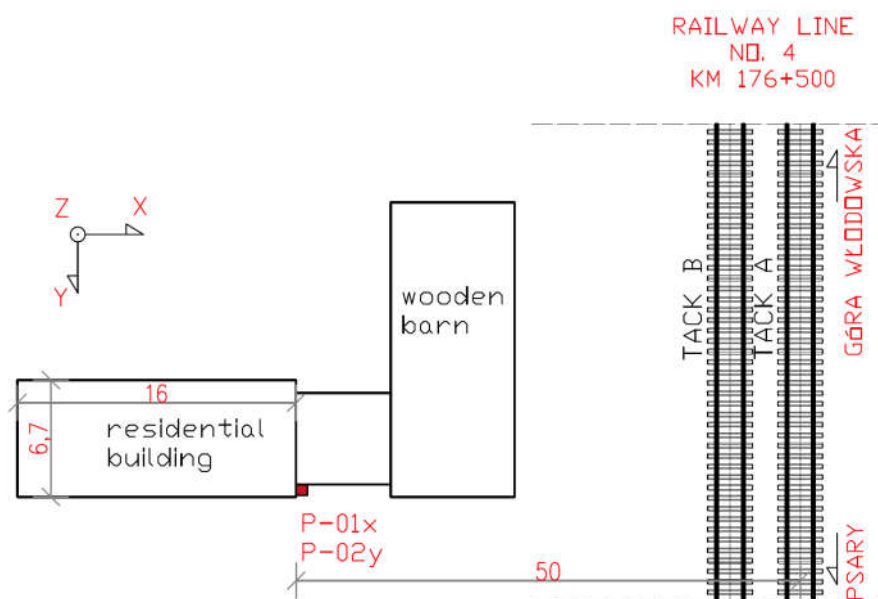


Figure 1. Measuring polygon – schematic arrangement of sensors.

3. Analysis

3.1. Analysis of time histories and SDI

All records of time history were analysed. Figure 2 shows the maximum values obtained from the time histories of the acceleration of horizontal components (P-01 x and P-02 y) of vibrations caused by passages of the Pendolino trains with speed 80-250 km/h.

The growth curves (exponential function) of maximum acceleration of vibration versus velocity of the train were fitted. It describes the dependence of the maximum acceleration of train speed. The coefficients of determination R^2 for both functions is above 0.9. Based on only these results it can be stated that the vibrations are increasing with the speed increase.

Nevertheless, scales of dynamic influences (SDI scales), Polish code [17] as mandatory recognizes not maximum values of vibration. Dimensions of the examined construction classify it as being within the scale SDI - II. By analyzing the results obtained according to the guidelines it was found that these vibrations are not harmful to the building considered as a whole structure. All acceleration values in one-third octave bands are located in the first zone of the SDI scale.

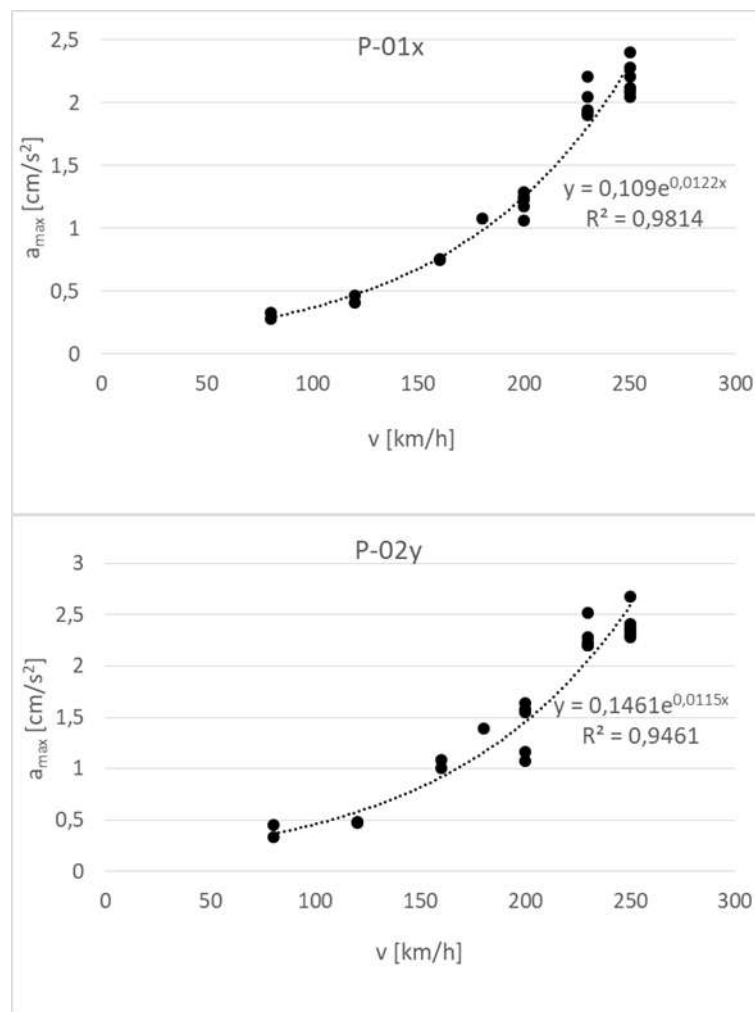


Figure 2. The maximum values from the recorded accelerations (the time histories) caused by trains at various speed.

3.2. Analysis of combination of WODB with ELECTRE I method

The indicator (WODB) is the maximum value of the ratio of the vibration acceleration parameters in one-third octave bands to the acceleration corresponding to the lower limit consideration of the dynamic influence on buildings due to the SDI scales in the same frequency band. WODB directly displays how many times the limit consideration of dynamic influence on construction has been exceeded. The harmful of vibrations is considered in the 1/3 octave bands up to 100Hz. Therefore, there are twenty – one frequency bands. Each event (a single passage of a train) generates 21 indicators. Therefore, comparing two events is no longer as easy as for maximum acceleration value (a_{max}). It requires the use of more complex methods, which provides sensible and straightforward rankings.

The purpose of applying ELECTRE is to evaluate whether higher velocity always produces higher vibrations. It is compared events at seven different speeds. The criterion is only WODB value for twenty-one bands. Each band is considered equivalent, therefore the weight is not introduced. In addition, in any considered case threshold of vibration harmfulness is not exceeded (first zone of the SDI) resulting there had not to be implemented activities to reduce the level of induced vibrations. In order to emphasize the various dependencies, different thresholds were used in the range of 0.5-0.6. The resulting matrix and graph ranking are shown in Figures 3-4. The relationship between the different thresholds and the two sensors varies. However, repetitive dependencies could be noticed. A train ride at a speed of 180km/h does not affect the environment much more than one at a speed of 160km/h. For the sensor P-01x and at threshold 0.6 and 0.7 it is clearly seen, that we have speed bands within which speed increases will not produce significantly greater vibrations (e.g. 80-120km/h; 160-

180km/h; 200-230km/h). Vibrations perpendicular and parallel to the axis of the track are not always equally sensitive to speed variations. Another significant conclusion concerns a speed of 200 km/h. Maximum acceleration value for this velocity does not take very deviating values from velocity 180km/h. The WODB indicator is rather on the level WODB corresponding to train velocity equal to 230 and 250km/h. Moreover, even for some frequency bands it is better to increase the speed to 250 km/h in order to reduce the vibration.

	P-01x								P-02y							
	v	80	120	160	180	200	230	250	v	80	120	160	180	200	230	250
0,5	80	1	1	1	1	1	1	1	80	1	1	1	1	1	1	1
	120	0	1	1	1	1	1	1	120	0	1	1	1	1	1	1
	160	0	0	1	0	1	1	1	160	0	0	1	0	1	1	1
	180	0	0	1	1	1	1	1	180	0	0	1	1	1	1	1
	200	0	0	0	0	1	1	1	200	0	0	0	0	1	1	1
	230	0	0	0	0	0	1	1	230	0	0	0	0	0	1	1
	250	0	0	0	0	0	0	1	250	0	0	0	0	0	0	1
0,6	v	80	120	160	180	200	230	250	v	80	120	160	180	200	230	250
	80	1	0	1	1	1	1	1	80	1	1	1	1	1	1	1
	120	0	1	1	1	1	1	1	120	0	1	1	0	1	1	1
	160	0	0	1	0	1	1	1	160	0	0	1	0	1	1	1
	180	0	0	0	1	1	1	1	180	0	0	1	1	1	1	1
	200	0	0	0	0	1	0	1	200	0	0	0	0	1	1	1
	230	0	0	0	0	0	1	1	230	0	0	0	0	0	1	1
	250	0	0	0	0	0	0	1	250	0	0	0	0	0	0	1
0,7	v	80	120	160	180	200	230	250	v	80	120	160	180	200	230	250
	80	1	0	1	1	1	1	1	80	1	0	1	0	1	1	1
	120	0	1	1	1	1	1	1	120	0	1	1	0	1	1	1
	160	0	0	1	0	1	1	1	160	0	0	1	0	0	1	1
	180	0	0	0	1	1	1	1	180	0	0	0	1	0	1	1
	200	0	0	0	0	1	0	0	200	0	0	0	0	1	1	1
	230	0	0	0	0	0	1	0	230	0	0	0	0	0	1	0
	250	0	0	0	0	0	0	1	250	0	0	0	0	0	0	1
0,8	v	80	120	160	180	200	230	250	v	80	120	160	180	200	230	250
	80	1	0	0	1	1	0	1	80	1	0	0	0	1	1	1
	120	0	1	0	1	1	0	1	120	0	1	0	0	0	1	0
	160	0	0	1	0	0	0	0	160	0	0	1	0	0	0	0
	180	0	0	0	1	0	0	0	180	0	0	0	1	0	1	0
	200	0	0	0	0	1	0	0	200	0	0	0	0	1	0	0
	230	0	0	0	0	0	1	0	230	0	0	0	0	0	1	0
	250	0	0	0	0	0	0	1	250	0	0	0	0	0	0	1
0,9	v	80	120	160	180	200	230	250	v	80	120	160	180	200	230	250
	80	1	0	0	0	1	0	0	80	1	0	0	0	1	1	0
	120	0	1	0	0	0	0	0	120	0	1	0	0	0	0	0
	160	0	0	1	0	0	0	0	160	0	0	1	0	0	0	0
	180	0	0	0	1	0	0	0	180	0	0	0	1	0	0	0
	200	0	0	0	0	1	0	0	200	0	0	0	0	1	0	0
	230	0	0	0	0	0	1	0	230	0	0	0	0	0	1	0
	250	0	0	0	0	0	0	1	250	0	0	0	0	0	0	1

Figure 3. The resulting matrix of ELECTRE I method.

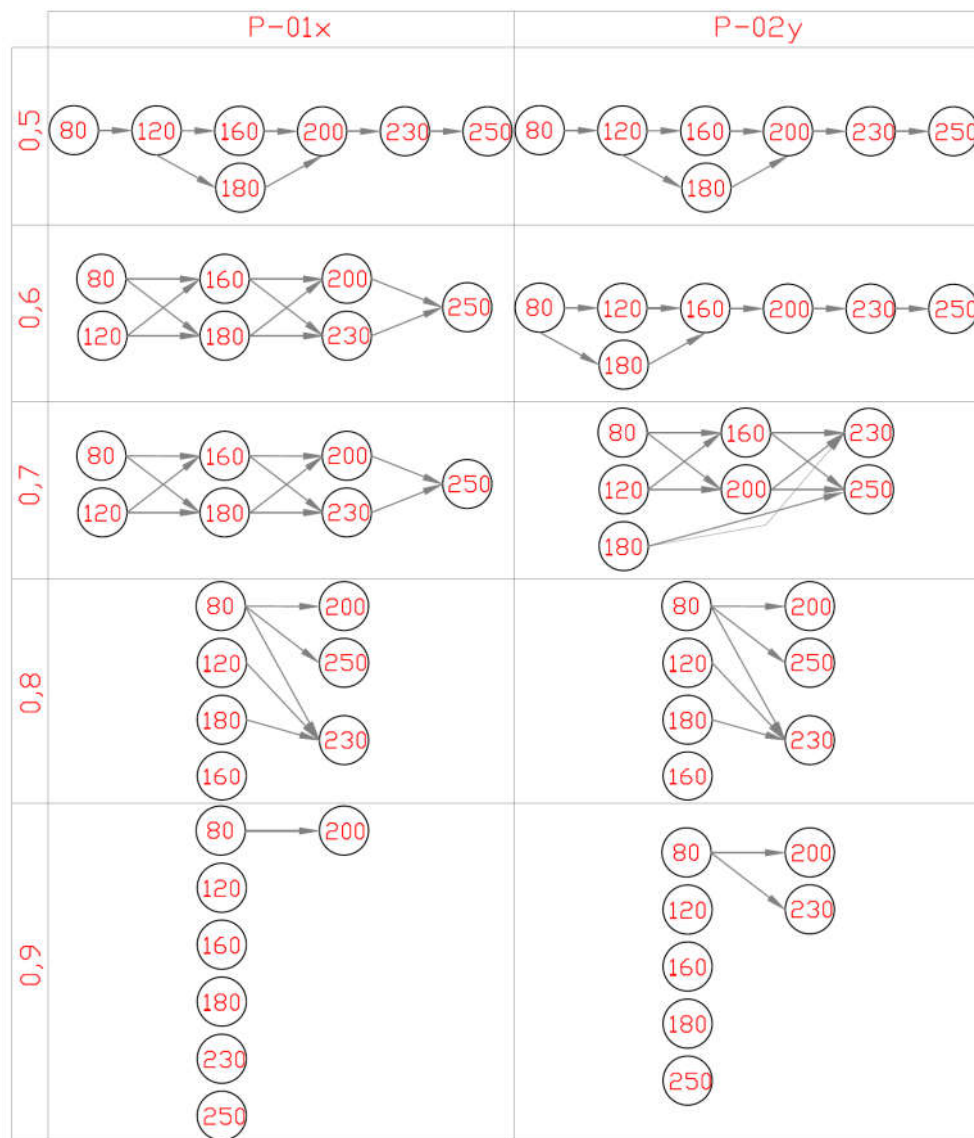


Figure 4. Ranking of speed preferences.

4. Conclusion

This study deals with the negative impact on surrounding structures caused by the passage of the Pendolino trains. Based on the analysis, we can draw the following conclusions:

- The limits specified by Polish standard in any of the occurrences of train passage were not exceeded. The train has been put into service.
- Maximum values obtained from the time history of the acceleration (a_{\max}) shows the upward / downward trend of vibration but it is not an indicator recognized by the standard. Because it is only a single peak, it may mislead or underestimate the total vibration level.
- Propagation of vibrations induced by trains with their effect on the structural response of construction is a complex phenomenon. It is difficult to assess the influence of vibration on buildings without in situ measurements. A train moving on a track at variable speed does not uniformly make the vibration higher in each frequency band.
- Standard indicators can successfully be treated as a multi-criterion problem. The use of analyzes e.g. from the family of ELECTRE could supplement the obtained information and highlight the omitted phenomena and dependencies.

Acknowledgments

The authors are grateful to the staff of the Laboratory of Structural Mechanics at Cracow University of Technology. In situ investigations of vibrations were performed by the laboratory.

The authors acknowledge the support of research funded by the Ministry of Science and Higher Education – project L-4/391/2017/DS-M.

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