The Impact of Bus and Tram Speed on Buildings and Residential Comfort

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Abstract

Bus and tram traffic in urban environments generates mechanical vibrations that can threaten both the structural integrity of buildings and the well-being of residents. The intensity of these effects is determined by many factors, including the quality of roads or tracks, the type of vehicles used, the distance of buildings to vibration sources, and the speed of their travel. The question is, can speed have a decisive influence on the generation of ceiling vibrations and the comfort of its residents? The operation of buses and trams can cause significant discomfort, especially in residential areas located in the immediate vicinity of roads and tram tracks. Such disturbances can negatively affect the quality of life, causing sleep disorders, increasing stress levels, and reducing concentration or productivity. The presented work shows the results of experimental studies on vibration comfort in buildings, specifically regarding the speed of passing trams and buses.

Keywords: *building vibrations, trams transport vibration, bus transport vibration, emission of vibration, vibration influence on people inside buildings, transport vibrations, emission of pollutants from the communication*

1. Introduction

For many years, the Building Vibration Laboratory at the Kraków University of Technology has been researching the impact of vibrations on building structures and the people inside them. Recently, their research interests have included the impact of vibrations on people in buildings from popular sources of communication in many cities, not only in Europe. Many urban transport engineers believe that limiting travel speed has a decisive influence on the level of generated vibrations. This publication presents experimental research on the impact of vibrations from tram and bus travel, depending on travel speed and the number of stories in the building. The results concern two selected buildings. Similar analyses focused on the influence of transport vibrations on human perception are available in the literature [1-8]. Many of these analyses focus on only one source of vibration. Some investigations focus on railway-induced vibrations and their influence [1-10]. Some studies describe the influence of vibrations on people inside buildings [11-13], but there is no data on the velocity of the source or its impact on people inside buildings [14].

2. Receiver – building

The study covered two buildings. One is a typical, four-story brick building with a basement and a rectangular floor plan. It is located approximately 32 meters from the nearest traffic lane and 40.5 meters from the edge of the nearest track. The second building was constructed using column-slab technology with infill. It has nine stories and an underground garage. It is approximately 15 meters from the nearest traffic lane and 27 meters from the edge of the nearest track.

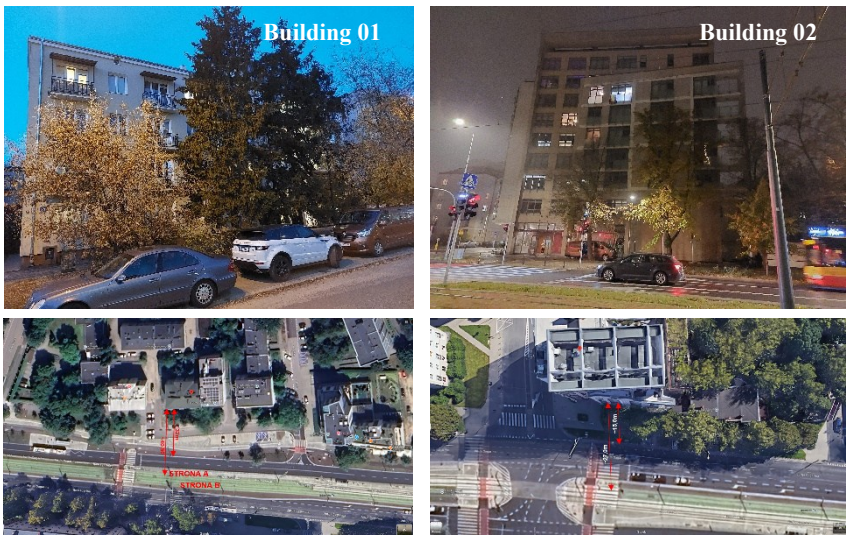

Fig. 1. General view of measured buildings, and it's location.

3. Criterion factor

The WODL ratio [13, 14] (the human vibration perceptivity ratio) is the best criterion for comparing a large amount of data. It is a measure of human vibration sensitivity. It is the ratio of the maximum root mean square (RMS) value obtained from the analysis to the vibration sensitivity threshold in the same frequency band, regardless of direction (Figure 1). The value of the WODL ratio is provided with the central frequency of the 1/3 octave band in which it is determined. Floor vibrations are measured to determine them, and then the obtained values are compared to the standard values described in [14] after the analysis. It should be noted that the WODL ratio is a more sensitive criterion than the impact of vibrations on the building structure because, before vibrations are felt through the building structure, people's perception and comfort thresholds will have been exceeded. The Polish standard [14] introduced the WODL ratio. The WODL ratio directly indicates how many times the threshold for perceiving vibrations has been exceeded.

This index was used as the primary criterion for comparing the results of the measurements.

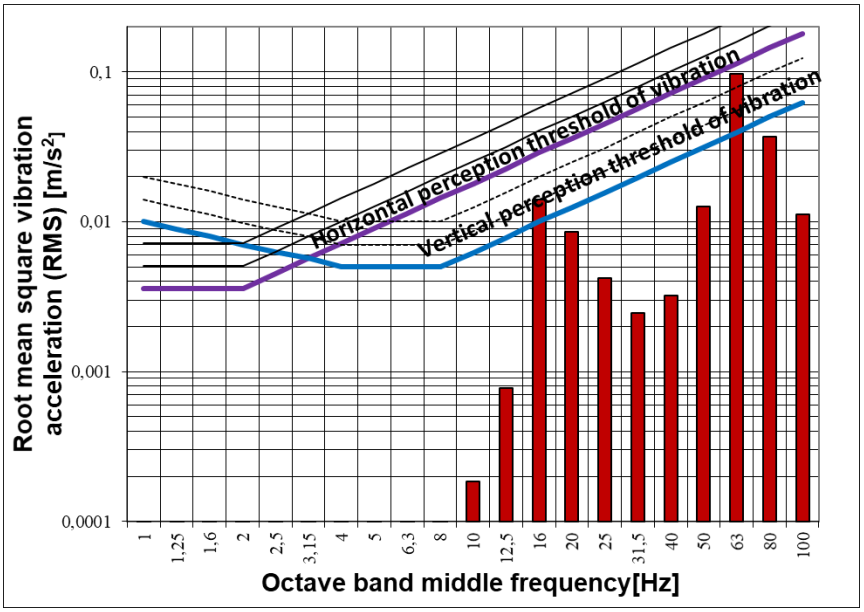

Fig. 2. Perception thresholds on people inside buildings [compare 13]

4. Source of vibration - buses and trams

Despite passing on different types of trams and buses, there was a divide between the two main groups of excitement: the bus and the tram. Each group has, in general, a very small fluctuation concerning the dynamic effect on people inside buildings. It's important to mention, the road and tracks were recently renovated. Otherwise, we could observe a higher level of dynamic interactions.

Fig. 3. Sources of vibration (left - tram, right – bus).

5. Methodology of Measuring

The main aim of the measurements was to determine the impact of vibrations on people in buildings [14]. These measurements were carried out after the general renovation of the tram line and the road. We didn't expect any exceed of the perception threshold, but it was a good opportunity to check what the difference is between the impact of vibrations on people in buildings from trams and buses in function of velocity by [13]. The tests were carried out on normal traffic with additional measurements of the speed of heavy vehicles (like trams and buses).

Under consideration, results were taken from sensors installed inside the measured buildings on the lowest floor and the highest (if it was possible). The apartments are private, so we have to get permission to make the measurements. Sometimes it was complicated.

Sensors were positioned on the heavy plate (30 kg) in the geometric center of the ceiling. Three mutually perpendicular sensors were mounted on every plate, two in the horizontal direction (X, Y) and one in the vertical direction (Z).

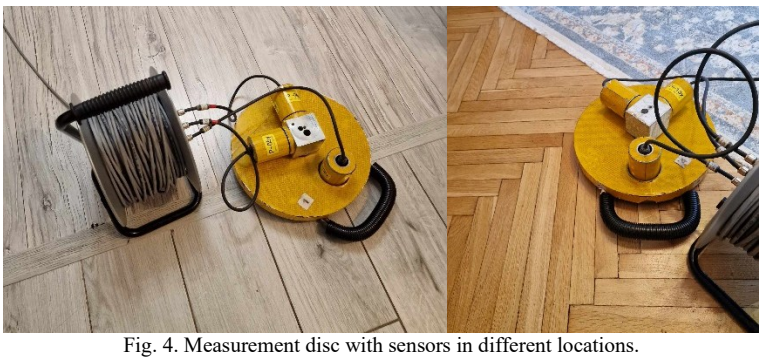

Fig. 4. Measurement disc with sensors in different locations.

The signal was measured with the use of seismic sensors PCB PIEZOTRONICS type 393B12 with a sensitivity of 10V/g and a measuring range of ± 0.5g, which perfectly meet the requirements for low-frequency measurements. Data was recorded using the Scadas Mobile multi-channel LMS analyzer.

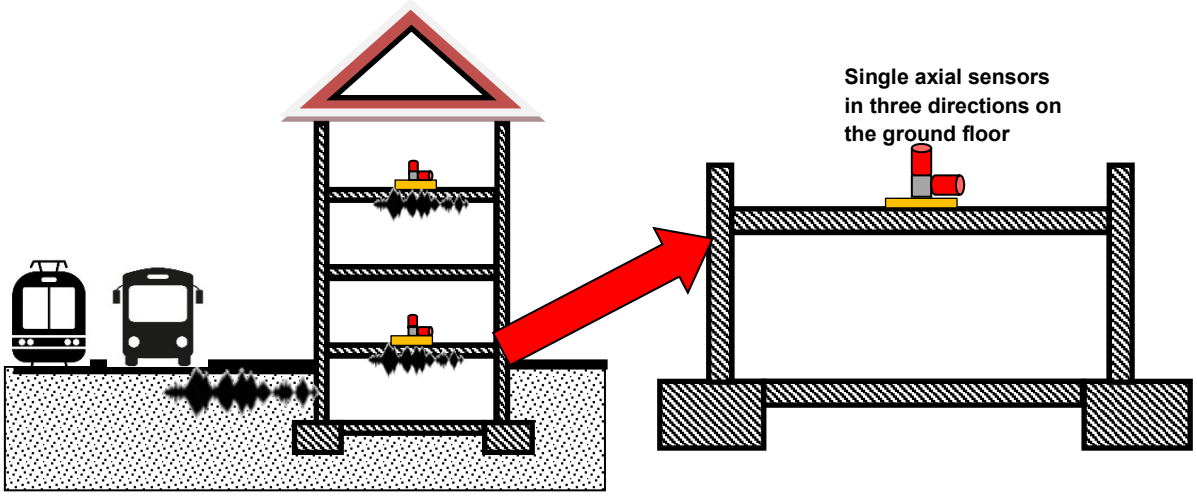

Fig. 5. Schematic of measurement situation with respect to both sources: busses and trams.

6. Results of measurements

The results of experimental measurements on two buildings with trams and buses passing nearby are presented below. The data presented were calculated as a WODL factor, meaning the ratio of human vibration perceptiveness. To better illustrate the trend of the values, the graph shows a line representing a second-order polynomial. It shows how the values of WODL are changing as a function of increasing the speed of the tram and bus.

Results were divided according to floor (ground floor and 3rd or 4th floor) and direction of vibration. There were measured all three orthogonal directions, X, Y, and Z (compare Fig. 4 and Fig. 5).

Tab. 1. Example trams passages in the neighbourhood of the building 01.

Vehicle type	Tram type	Side	Speed [km/h]	P-04x		P-05y		P-30z		P-07x		P-08y		P-09z	
				Disc Ground Floor								Disc 3rd Floor			
				f [Hz]	WODL	f [Hz]	WODL	f [Hz]	WODL	f [Hz]	WODL	f [Hz]	WODL	f [Hz]	WODL
Tram	120Na	A	17	63	0.01	63	0.01	50	0.03	4	0.02	31.5	0.02	12.5	0.24
Tram	140N	B	27	63	0.008	63	0.007	31.25	0.029	8.25	0.017	31.5	0.025	12.5	0.707
Tram	140N	A	28	63	0.007	63	0.006	56.5	0.022	4	0.020	31.5	0.021	12.5	0.243
Tram	140N	B	29	50	0.01	63	0.01	50	0.03	4	0.02	31.5	0.02	12.5	0.22
Tram	140N	A	29	50	0.03	63	0.03	40	0.15	4	0.02	31.5	0.01	12.5	0.21
Tram	140N	A	31	63	0.01	63	0.01	50	0.03	4	0.02	31.5	0.03	12.5	0.96
Tram	140N	B	32	63	0.01	63	0.01	63	0.02	4	0.02	31.5	0.02	12.5	0.30

Tab. 2. Example busses passages in the neighbourhood of the building 01.

Vehicle type	Side	Speed [km/h]	P-04x		P-05y		P-30z		P-07x		P-08y		P-09z	
			Disc Ground Floor								Disc 3rd Floor			
			f [Hz]	WODL	f [Hz]	WODL	f [Hz]	WODL	f [Hz]	WODL	f [Hz]	WODL	f [Hz]	WODL
Bus	B	18	63	0.0079	16	0.0100	63	0.0226	4	0.0117	31.5	0.0125	12.5	0.2459
Bus	A	21	63	0.0461	63	0.0361	63	0.0646	50	0.0329	12.5	0.0173	12.5	0.7687
Bus	A	25	10	0.0056	63	0.0041	10	0.0371	12.5	0.0199	31.5	0.0368	12.5	0.7198
Bus	B	26	63	0.0141	63	0.0090	50	0.0396	4	0.0103	31.5	0.0229	12.5	0.3743
Bus	B	29	63	0.0080	63	0.0078	10	0.0280	12.5	0.0156	31.5	0.0209	12.5	1.1056
Bus	A	30	63	0.0120	63	0.0125	63	0.0415	4	0.0218	31.5	0.0190	12.5	0.9189
Bus	A	31	50	0.0069	63	0.0067	50	0.0252	12.5	0.0124	31.5	0.0178	12.5	0.5402

Tab. 3. Example trams passages in the neighbourhood of the building 02.

Vehicle type	Tram type	Side	Speed [km/h]	P-04x		P-05y		P-30z		P-07x		P-08y		P-09z	
				Disc Ground Floor						Disc 4th Floor					
				f [Hz]	WODL	f [Hz]	WODL	f [Hz]	WODL	f [Hz]	WODL	f [Hz]	WODL	f [Hz]	WODL
Tram	140N	A	29	50	0.0022	40	0.0026	40	0.0543	2	0.0090	3	0.0062	10	0.0139
Tram	128N	B	30	2	0.0022	50	0.0018	50	0.0482	2	0.0100	3	0.0057	13	0.0199
Tram	140N	B	30	11	0.0068	8.25	0.0027	35	0.1133	2	0.0137	6.25	0.0095	11.25	0.0688
Tram	140N	A	34	10	0.0031	40	0.0028	40	0.0695	2	0.0123	3	0.0077	10	0.0496
Tram	140N	B	35	25	0.0076	50	0.0039	25	0.0973	2	0.0110	3	0.0077	13	0.0183
Tram	128N	B	35	10	0.0046	50	0.0023	50	0.0676	2	0.0106	2	0.0092	10	0.1007
Tram	128N	A	35	2	0.0029	40	0.0023	50	0.0505	2	0.0163	3	0.0086	13	0.0186

Tab. 4. Example busses passages in the neighbourhood of the building 02.

Vehicle type	Side	Speed [km/h]	P-04x		P-05y		P-30z		P-07x		P-08y		P-09z	
			Disc Ground Floor						Disc 4th Floor					
			f [Hz]	WODL	f [Hz]	WODL	f [Hz]	WODL	f [Hz]	WODL	f [Hz]	WODL	f [Hz]	WODL
Bus	A	15	10	0.0025	2	0.0015	25	0.0225	2	0.0081	2.5	0.0088	10	0.0399
Bus	A	20	10	0.0039	2	0.0022	37.7	0.0372	2	0.0098	2.3	0.0113	10.8	0.0524
Bus	A	24	10	0.0030	2	0.0016	50	0.0268	2	0.0137	2.5	0.0073	10	0.0377
Bus	A	25	10	0.0064	12.5	0.0018	25	0.0300	2	0.0080	10	0.0124	10	0.2003
Bus	B	27	12.5	0.0033	12.5	0.0017	31.5	0.0380	2	0.0170	2	0.0078	12.5	0.0546
Bus	A	27	16	0.0042	16	0.0016	16	0.0572	16	0.0154	2.5	0.0063	16	0.0898
Bus	A	30	10	0.0035	7.25	0.0017	50	0.0346	2	0.0097	2.5	0.0097	45	0.0396

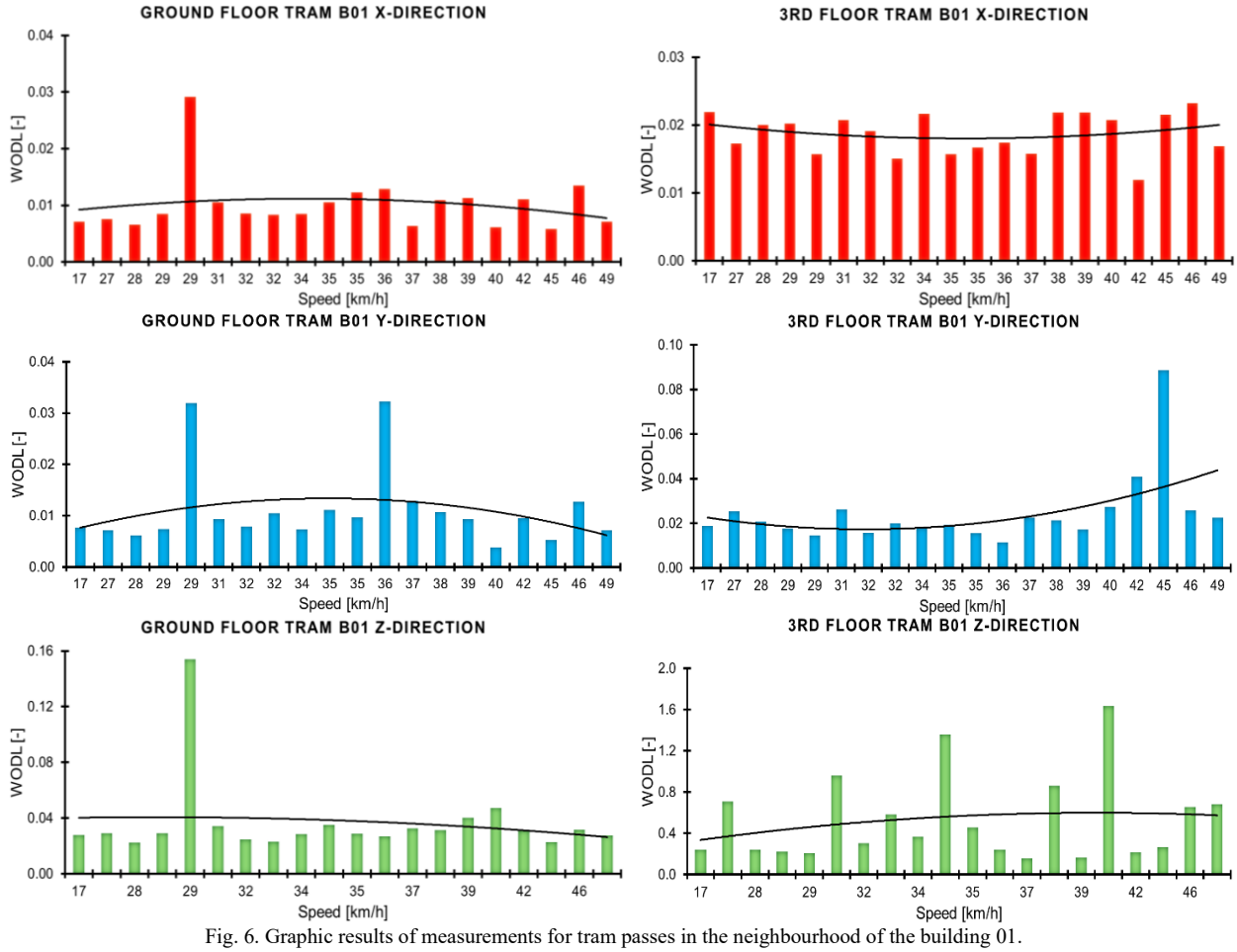

Fig. 6. Graphic results of measurements for tram passes in the neighbourhood of the building 01.

Building 01 is a typical four-story brick building with a basement and a rectangular floor plan. It is representative of a large group of similar buildings in our country.

As we can see from the trend line, the main difference is the level of the building. For the ground floor, the level of vibration feeling (WODL) is low with low speed, grows with middle speed, and decreases with increasing velocity of passing trams (in all directions).

The situation on the third floor is different: low and high speeds of tram passage result in higher vibration levels (WODL), but middle speed results in lower levels. This occurs in two horizontal directions. In the vertical direction (Z), the WODL factor increases with the velocity of the tram.

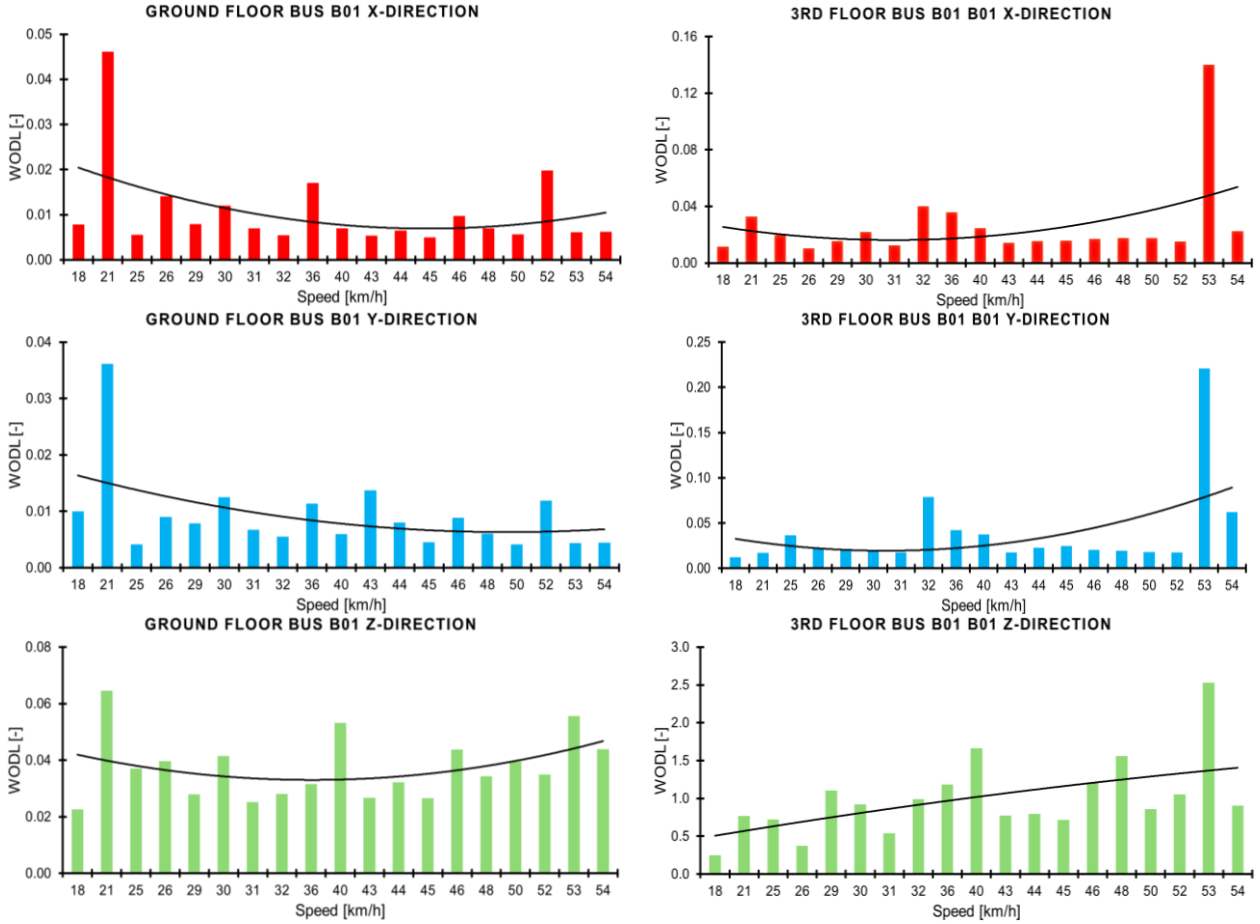

Fig. 7. Graphic results of measurements for bus passes in the neighbourhood of the building 01.

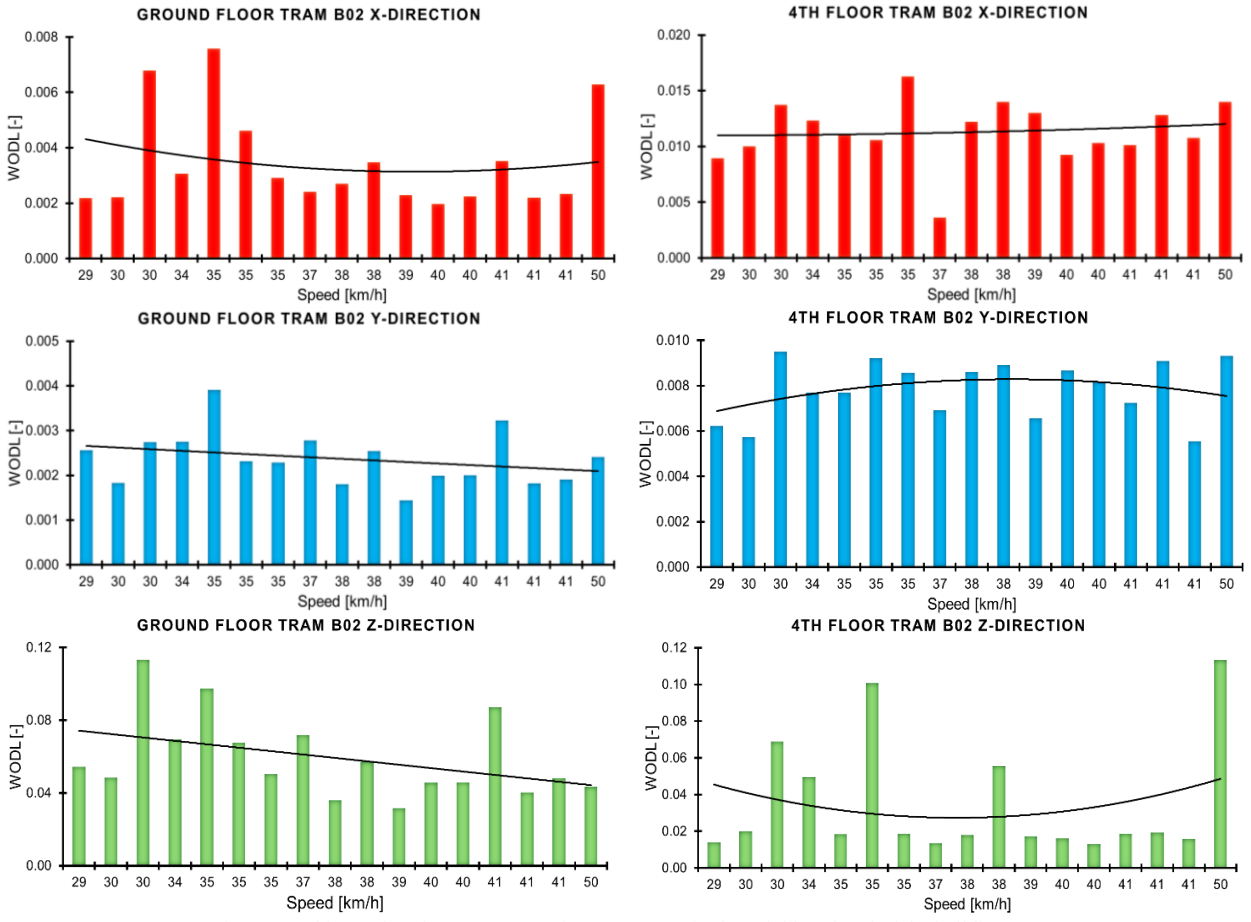

Fig. 8. Graphic results of measurements for tram passes in the neighbourhood of the building 02.

The trend line for bus passages reveals an interesting observation for the ground floor: lower bus speeds result in higher WODL values. For the third floor, however, the trend line indicates an increase in dynamic impacts as the speed of the passing bus increases.

Building 02 was constructed using column-slab technology with infill. It has nine stories and an underground garage. It is a modern construction that is much heavier than Building 01. Therefore, we can expect some differences concerning dynamic interactions.

For tram passages on ground level, we can observe that increasing tram speed causes lower dynamic effects (WODL factor). The situation is more complicated on the fourth floor, which was the highest floor accessible for measurement purposes. The direction of the vibration influence changes. It appears insensitive to the horizontal X direction. For the horizontal Y direction, low speed causes a low level of vibration (WODL), which grows with middle speed and decreases with increasing velocity of passing trams. For the vertical Z direction, both low and high tram passage speeds produce higher vibration levels (WODL), but middle speed produces lower levels.

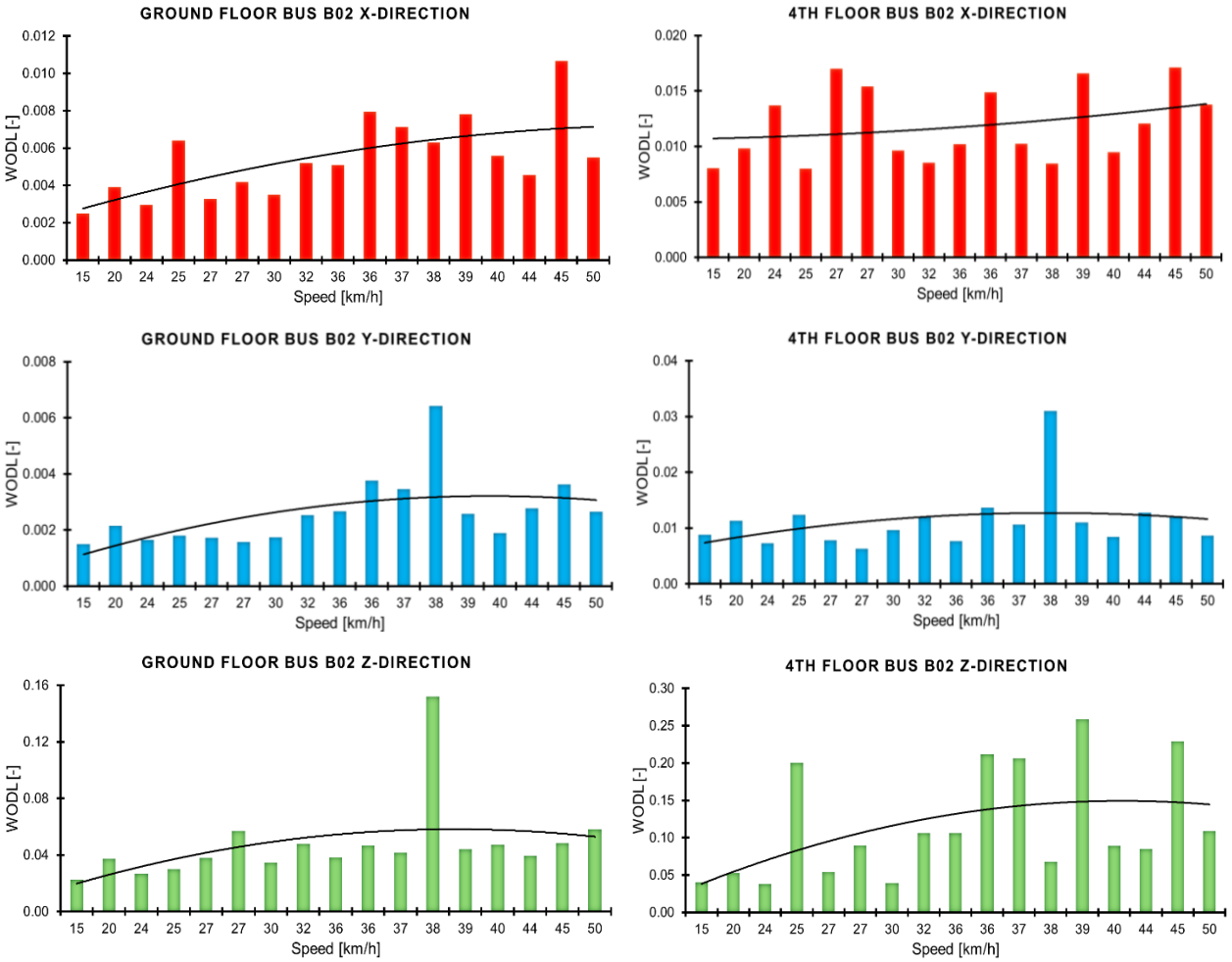

Fig. 9. Graphic results of measurements for bus passes in the neighbourhood of the building 02.

For bus passages, we can observe that there are no differences concerning stories. The dynamic interaction trend looks similar on the ground and fourth floors. The higher the speed, the greater the dynamic effect recorded on the measured ceiling.

The speed of public transportation appears to be a parameter that, as it increases, should generate greater dynamic sensations in terms of how people perceive vibrations in buildings located in the immediate vicinity. However, based on in situ studies, observations were made on two buildings of different designs that do not confirm this thesis. The study covered two types of vehicles: trams and buses. Significant differences were observed between the two types of vehicles and the floors on which the vibrations were recorded. Interestingly, for both buildings, a decrease in recorded vibrations was observed on the ground floor as tram speed increased. This upward trend is characteristic of the higher measured floor.

In summary, the level at which people perceive vibrations in buildings increases with the type of vehicle generating the vibrations and depends on the floor on which people are standing.

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