The Impacts of Truck Vibration on the Communities Along the Highway Road No 12, Phitsanulok

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Abstract. *The purpose of this research is to analyze the vibration effect from different types of trucks passing through interprovincial highway road No. 12 to the community areas. The Peak Particle Velocity and frequency of Zero crossing and Fast Fourier Transform of an individual truck running on a highway road were obtained by the vibration meter. In the first experiment, vibration and speed data were collected from 238 identified trucks weighing from 5 to 50.5 tons and speeds ranging from 51 to 80 km/hr. All these experiment trucks run through the highway balance station regarding weight inspection with camera records. The second experiment was conducted by installing the vibration meter on two buildings located by the roadside in the community area, which is adjacent to the traffic light. The results showed that the vibrations generated by trucks were dominated by vertical waves and Peak Particle Velocity was correlated with the weight and speed of trucks. Interestingly, significant differences in vibration data between two types of trucks, semi-lorry and full-lorry trucks, were found. The impact of vibration on the community was minimized following the Deutsches Institut fur Normung E.V. (DIN) standard which had no significant effect on buildings and the vibration perception was at a level where it was possible to feel the vibration when compared to the guidelines by Whiffin and Leonard.*

Keywords:

Ground-borne vibration, Traffic-induced Ground vibration, Peak particle velocity, Highway, Building damage.

1. Introduction

Most of the goods land freight in Thailand were transported by trucks [1]. Communities along both local and interprovincial highway roads have possibly experienced the impacts of vibration from trucks. This impact could damage the buildings and disturb human well-being, particularly during the night. The vibrations originating from trucks were significantly different from those of passenger cars due to the higher body and capacity loading weight [2, 3]. The movement of truck lorries would cause the vibration wave to run through the road surface and soil substrate which may affect buildings located near the road [4]. Truck weight is considered the cause of more dynamic load on roads than passenger cars, and it potentially damages road structures. Moreover, vibration generated from trucks was significantly increased which is depended on the condition of the road surface. This would be due to the impact force between the tire and the road surface. Several studies have demonstrated a highly significant correlation between the vibration and speed of vehicles [5-11]. The vibration can be measured by the instrument which attaches the device to the object's surface. The instrument generally reports the data regarding the speed velocity of particle movement from three axis: X, Y and Z. Also, the frequency of waves that were generated during the vibration was mostly read as Zero Crossing (ZC) and Fast Fourier Transform (FFT). Furthermore, there were certain levels of vibration which set as the international standard to prevent excessive vibration for both human perception and building structures such as DIN 4150-3 [12] and Whiffin and Leonard [13] the guidelines as shown in Table 1 and Table 2. This research aimed to investigate the vibration generated by several kinds of trucks which may impact the community along the highway.

Table 1 DIN 4150-3 Vibration criteria for the assessment of vibration to structures

Type of structure	Peak Particle Velocity PPV (mm/sec)			
	At foundation level Frequency range (Hz)			At floor level of topmost story (all frequencies
	< 10	10-50	50-100	
Commercial/Industrial	20	20-40	40-50	40
Residential	5	5-15	15-20	15
Sensitive/Historic	3	3-8	8-10	8

Table 2 Effects of Vibration on People and Buildings

PPV (mm/s)	Human Reaction	Effects on Buildings
0 - 0.15	Imperceptible	Unlikely to cause damage of any type
0.15 - 0.30	Threshold of Perception	Unlikely to cause damage of any type
2.0	Vibrations Perceptible	Effects ancient and historical monuments
2.5	Continuous exposure to vibration is annoying	Virtually no risk of architectural damage to normal buildings
5.0	Vibrations annoying to people in the buildings	Threshold for risk of architectural damage in house with plastered walls and ceilings
10 - 15	Continuous vibrations are unpleasant and unacceptable	Would cause architectural damage and possibly minor structural damage

2. Methodology

The interprovincial highway No. 12 in Ban Krang Subdistrict, Mueang District, Phitsanulok Province was selected as the studied site. The road surface of the selected site is asphaltic concrete. The experiment was divided into two parts, which were not related to each other. The first experiment was to collect the vibration parameters of trucks that traveled on the left-lane road. The vibration measurement station was set at Km 218+500 where the geophone was placed beside the road's hard shoulder (Fig. 1). The vibration meter, Instantel Inc model Micromate continuously collected the vibration data from 8.00 AM until 4.00 PM, eight hours of recording for ten days. The speeds and images of the truck were collected by the speed gun and video camera to identify truck driving license plates before passing the balance station to obtain the actual weight where it was almost two kilometers further away at Km 220+000.

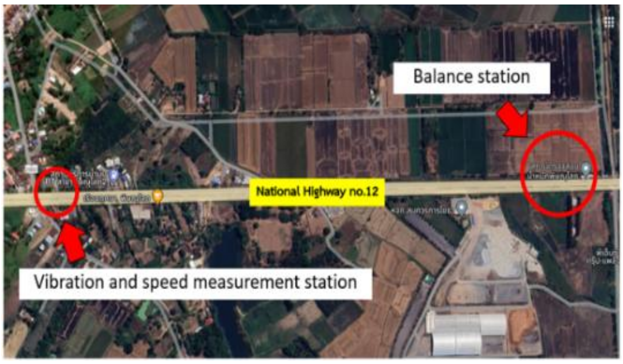

Fig. 1 The geophone installation and location along the tested road. Vibration and speed measurement station (16°54'43.9"N 100°11'14.1"E); Balance station (16°54'01.6"N 100°11'37.4"E).

The second experiment was conducted in the communities where road No. 12 passes by at KM 222+800. This intersection was considered all the weighed trucks from the balance station pass which may cause the vibration effect on the community surroundings. There are two buildings selected to be stations for collecting the vibration data. The geophone was attached to the ground floor which was made from concrete. The first building is located before the trucks enter the traffic lights, and there have been history complain record about the vibration caused by the trucks before. The second station is situated after the truck leaves the traffic light while trucks have heavy acceleration (Fig. 2). The road surface is a reinforced concrete structure. The geophone was attached to the floor of each building. The measurement period was 24 hours for 1 day regarding the vibration measurement standard method of the Pollution Control Department in Thailand [14]. The total recorded data from each building was 582 and 614 respectively.

Fig. 2 Two buildings were selected to be stations for collecting the vibration data. Building 1 (16°52'39.0"N 100°12'21.6"E); Building 2 (16°52'51.1"N 100°12'14.9"E).

The vibration meter, Instantel Inc, model Micromate was set to measure the vibration continuously by Triaxial Geophone range 1-315 Hz according to DIN 45669-1. The tricker for vibration measurement was set at 0.127 mm/s and recorded each event data for 3 seconds. Peak Particle Velocity (PPV), Zero Crossing (ZC) and Fast Fourier Transform (FFT) were analyzed by the THOR program, Instantel Inc (Desktop software platform to store and manage event data on a local computer). The total reading events measured in experiments 1 and 2 were 238 and 1,196 respectively. The vibration data obtained from experiment 1 was analyzed based on the weight types and speeds of trucks. The vibration data obtained from experiment 2 was analyzed by dividing based on time recorded in day and night. The statistical analysis was performed by One-Way ANOVA and Duncan's multiple-range test to find the significant differences in PPV and frequency wave between groups of truck speeds and weights. The correlation of truck weight and speed with PPV was performed by the Pearson Correlation test.

3. Results and Discussion

A. Experiment 1

There were vibration measurements from 238 trucks which were categorized into 6 groups based on the number of wheels: 6, 10, 12, 18, 22 semi-lorry, and 22 full-lorry

(Table 3 and Fig. 3). The results showed that the range of truck speed was recorded from 51 to 80 Km/h complying with the traffic speed regulation for truck. Which, speed range was categorized into three levels in this research, slow 51 - 60 Km/hr, moderate 61 - 70 Km/hr, and standard 71 - 80 Km/hr.

Table 3 The number of samplings for each type of truck

Types	Number of trucks	Weight range (tons)	Average weigh (tons)
6-Wheel truck, (a)	92	5.08 - 15	11.47 ± 2.89
10-Wheel truck, (b)	36	8 - 25	15.97 ± 6.18
12-Wheel truck, (c)	6	11.85 - 30	23.57 ± 6.81
18-Wheel truck, (d)	19	14.5 - 47	40.82 ± 10.71
22-Wheel truck (semi-lorry, (e))	18	22.08 – 50.5	41.96 ± 8.02
22-Wheel truck (full-lorry, (f))	67	19.94 – 50.5	48.61 ± 5.04

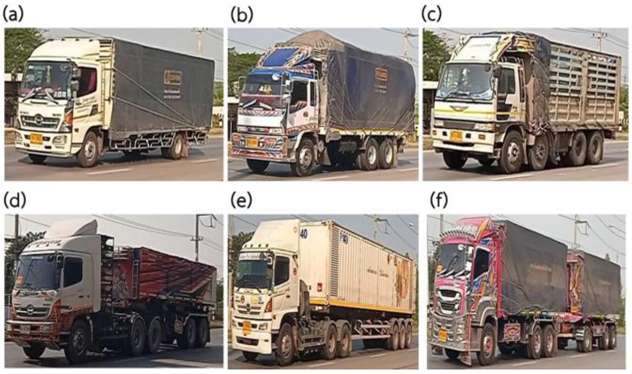

Fig. 3 Photo of truck types (a) 6 Wheels (b) 10 Wheels (c) 12 Wheels (d) 18 Wheels (e) 22 Wheels (semi-lorry) (f) 22 Wheels (full-lorry)

The PPV of each group was increased when truck speed increased from level 1 to level 3. These could be seen on the data of the z-axis (vertical wave) shown in Table 4. Most of the PPV from x and y axis (longitudinal and transverse) found that lower than the trigger set at 0.127. There was a very high significant difference in PPV (z-axis) between the groups of 6 and 22 wheelbases in all speed levels. This could be due to the differences in weight capacity and wheel movement on the road. Also, the 6-wheelbase truck ran at different speed levels and found that speed level 3 had an increasing PPV (z-axis) greater than level 1 by 20%. Moreover, the PPV (z-axis) from full-lorry 22 wheels was higher than 10 wheelbase trucks by 70% in speed level 2. Notably, the truck desire, the full-lorry 22 wheels could be equivalent to two 10-wheelbase trucks run together. Interestingly, a comparison between two types of trucks, the semi-lorry 22 wheels and full-lorry 22 wheels, found that the PPV (z-axis) was significantly increased by 47% from the semi-lorry 22 wheelbase type (Fig. 4 a and b). This could be the difference of number driving axils which caused more movement of the body and structure of trucks.

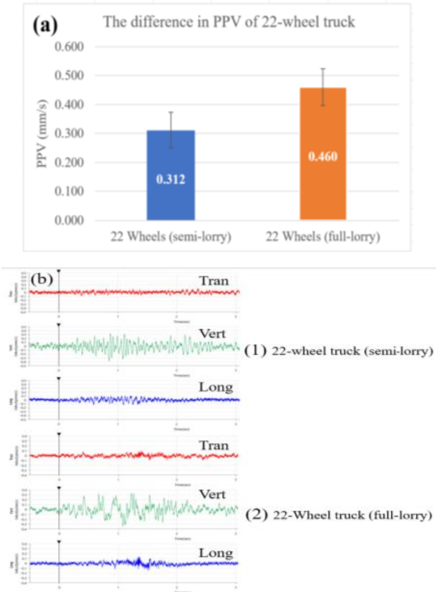

Fig. 4 (a) The difference in PPV of 22 wheels (z-axis). (b) Ground vibration induced by truck.

Therefore, the weight, speed, and type of truck were considered the key factors of variation in nearby structural vibration. The correlations of three groups of vibration data, the sum of PPV, ZC, and FFT with weight when the speed has changed from level 1 to level 3 were significant (Fig. 5 a-i). However, the relation of truck weight and speed with Zero Crossing and Fast Fourier Transform showed a reverse correlation with truck weight. This inverse correlation was significant at the low-speed level

Table 4 The table represents the truck vibration from the z-axis (Vertical wave) measured by geophone.

Types	Average of PPV 51 - 60 Km/h (mm/s)	Number of trucks	Average of PPV 61 - 70 Km/h (mm/s)	Number of trucks	Average of PPV 71 - 80 Km/h (mm/s)	Number of trucks
6-Wheel truck	0.177 ± 0.022	28	0.182 ± 0.035	40	0.212 ± 0.061	24
10-Wheel truck	0.245 ± 0.057	17	0.259 ± 0.066	10	0.366 ± 0.094	9
12-Wheel truck	0.324 ± 0.045	2	0.229 ± 0.016	3	0.347 ± 0.000	1
18-Wheel truck	0.311 ± 0.058	9	0.348 ± 0.111	7	0.447 ± 0.032	3
22-Wheel truck (semi-lorry)	0.341 ± 0.092	38	0.354 ± 0.062	7	0.312 ± 0.062	2
22-Wheel truck (full-lorry)	0.379 ± 0.091	9	0.439 ± 0.079	24	0.460 ± 0.064	5

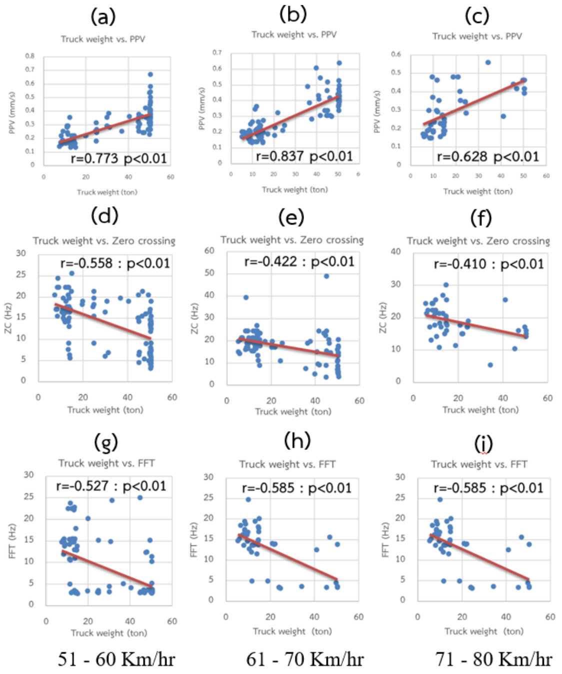

Fig. 5 The correlation between vibration data, (a-c) PPV, (d-f) ZC, and (g-i) FFT, with truck weight and speed level.

B. Experiment 2

There was a total of 1,196 events of vibration recorded from two buildings; (1) entering and (2) leaving the traffic light, The traffic light is located along Highway Road No.12 at KM 222+800 junction. The measured data was divided into two groups, building 1 comprises 582 events of vibration, and 614 events of vibration were collected from Building 2. The measurement showed that PPV (x,y,z), ZC (x,y,z) and FFT (x,y,z) obtained from building 1 were 0.134 – 0.315 mm/s, ZC: 4.7 – 100 (x), 4.5 – 100 (y), 2.9 – 20.5 (z) Hz and FFT: 2.0 – 30.0 (x), 2.0 – 96 (y) 2.5 – 19.2 (z) Hz respectively. The results of PPV (x,y,z), ZC (x,y,z) and FFT (x,y,z) obtained from building 2 were 0.134 – 0.410 mm/s, ZC, 3.8 – 100 (x), 3.9 – 100 (y), 1.6 – 64.0 (z) Hz and FFT: 2.0 – 49.5 (x), 2.0 – 23.0 (y), 2.5 – 59.0 (z) Hz. Comparing the average vibration and frequency results from Building 2 to Building 1 reveals significant differences in the PPV, FFT, and ZC, as shown in Table 5. The average PPV and frequency in Building 2 were larger than in Building 1, with the PPV, ZC, and FFT increasing by 10%, 32%, and 25% respectively. However, the vibration measured from both buildings was still below the standard limit of vibration to the building structure according to DIN 4150-3 (Table 1 and Fig. 6). This would ensure that no significant damage to both buildings was indeed by traffic vibration. Also, this level of vibration would not cause disturbing to human normal life. The differences in average vibration data from buildings 1 and 2 depend on the position of the building. Building 1 was located before the traffic light where most vehicle always reduces their speed during approaching. Therefore, the vibration could be reduced too. In contrast, the location of building 2 is passing of traffic light, all vehicles mostly accelerate to the travel speed. Moreover, there was no significant vibration during the day (6.00 AM-6.00 PM) and night (6.00 PM-6.00 AM) (Fig. 7).

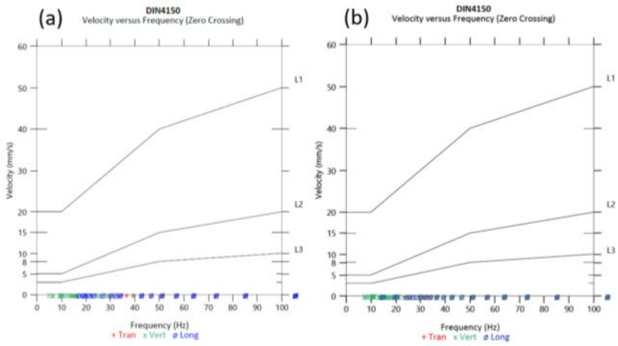

Fig. 6 The data represent the velocity vs frequency (Zero Crossing) from buildings 1 (a) and 2 (b) when compared with the Deutsches Institut fur Normung E.V. (DIN 4150-3) standard

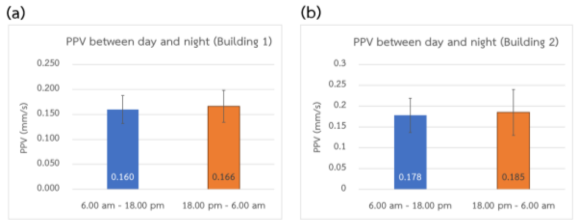

Fig. 7 The difference in PPV during day and night measurements of (a) Building 1 and (b) Building 2

Table 5 The data represent the vibration (PPV, ZC, and FFT) of building 1 and 2.

Building	Number of events	Average	t	P
1 (PPV)	582	0.162 ± 0.029	7.302	.000
vs				
2 (PPV)	614	0.179 ± 0.045		
1 (ZC)	582	10.2 ± 3.5	10.666	.000
vs				
2 (ZC)	614	13.5 ± 6.8		
1 (FFT)	582	6.8 ± 6.5	4.713	.000
vs				
2 (FFT)	614	8.5 ± 5.7		

* The significant level is .05

4. Conclusion and Recommendations

This research was designed to obtain the vibration data from the original truck which regularly runs on the highway road. Two main key elements, the weight and speed of individual trucks, were vital for data analysis. Several research has been conducted to investigate the impact of vibration from traffic [15-17], but the most difficult part is to set up the video camera and weighting through the balance station to identify trucks. This was very helpful in measuring the actual vibration from running trucks. The condition of the road surface which is made from reinforced concrete perhaps in good condition flat and smooth could significantly reduce some effects when the truck passes through the community. However, there were some occasions when the truck was trying to speed across the traffic light, causing more vibration.

The results of this research showed that the PPV were significantly affected by increasing the weight and speed of trucks. This was similar to the research of Watts and Fozi et al. [18, 19], which found that there is an obvious trend of rising PPV with increasing vehicle weight and the speed of the vehicle increases. In contrast, the decrease of ZC and FFT would be found in the heavier trucks. Ainalis et al. [20] obtained FFT and ZC from the heavy trucks and found that the FFT and ZC decreased as well. Interesting data was found from the semi-lorry 22 wheels and full-lorry 22 wheels which showed significant finding of vibration between two types. This could be supported by the reinforcement of vibration which was generated from two bodies of full-lorry 22 wheel. The first section, the truck with engine and loading compartment and the second section, only the loading compartment was connected by a flexible connector. Consequently, the reinforcement of vibration from two sources was generated together which caused more vibration than the semi-lorry 22 wheels to which the body was attached. There was research providing evidence about reinforcement associated the stronger vibration when the source causes vibration almost simultaneously [21].

In conclusion, 1) this research found that the speed, weight and type of trucks significantly influence vibration, particularly when the speed of the truck increases. 2) The heavier truck running at the same speed caused more ZC and FFT, which may cause a high impact on the building structure along the road. 3) The lower speed could prevent excessive vibration from trucks passing through the community. 4) To prevent damage to the road and bridge structures the vibration monitoring system should be installed to record the vibration data which must be useful for maintainance planning.

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References

[1] NESDC, "Thailand s Logistics Report 2022," pp. 1-12, 2022. [Online]. Available: https://www.nesdc.go.th/download/logistics/report/LogisticsReportTH.pdf.

[2] P. Asnachinda, "A Study of Personal Vibration Perceptibility of Buraphavithi Elevated Expressway," The 25th National Convention on Civil Engineering, vol. 25, pp. INF06-INF06, 2020.

[3] T. Astrauskas, R. Grubliauskas, and T. Januševičius, "Investigation and Evaluation of Speed Table Influence on Road Traffic Induced Ground Borne Vibration," in Environmental Engineering. Proceedings of the International Conference on Environmental Engineering. ICEE, 2017, vol. 10: Vilnius Gediminas Technical University, Department of Construction Economics, pp. 1-7, doi: 10.3846/enviro.2017.002.

[4] O. Hunaidi, Traffic vibrations in buildings. Citeseer, 2000.

[5] M. O. Al-Hunaidi and J. Rainer, "Remedial measures for traffic-induced vibrations at a residential site. I. Field tests," Canadian Acoustics, vol. 19, no. 1, pp. 3-13, 1991.

[6] M. Agostinacchio, D. Ciampa, and S. Olita, "The vibrations induced by surface irregularities in road pavements–a Matlab® approach," European Transport Research Review, vol. 6, no. 3, pp. 267-275, 2014, doi: 10.1007/s12544-013-0127-8.

[7] G. Watts and V. Krylov, "Ground-borne vibration generated by vehicles crossing road humps and speed control cushions," Applied Acoustics, vol. 59, no. 3, pp. 221-236, 2000, doi: 10.1016/S0003-682X(99)00026-2.

[8] J. J. Hajek, C. T. Blaney, and D. K. Hein, "Mitigation of highway traffic-induced vibration," in 2006 Annual Conference of the Transportation Association of Canada, 2006: Citeseer, pp. 1-13.

[9] M. A. Lak, G. Degrande, and G. Lombaert, "The effect of road unevenness on the dynamic vehicle response and ground-borne vibrations due to road traffic," Soil dynamics and earthquake engineering, vol. 31, no. 10, pp. 1357-1377, 2011, doi: 10.1016/j.soildyn.2011.04.009.

[10] R. Zhou, L. Yan, B. Li, and J. Xie, "Measurement of truck transport vibration levels in China as a function of road conditions, truck speed and load level," Packaging Technology and Science, vol. 28, no. 11, pp. 949-957, 2015, doi: 10.1002/pts.2176.

[11] H. M. Shiferaw, "Measuring traffic induced ground vibration using smartphone sensors for a first hand structural health monitoring," Scientific African, vol. 11, p. e00703, 2021, doi: 10.1016/j.sciaf.2021.e00703.

[12] D. I. f. Normung, "DIN 4150-3: Structural vibrations–Part 3: Effects of vibration on structures," ed: German Standards Organization (GSO) Berlin, 1999.

[13] A. Whiffin and D. Leonard, "A survey of traffic induced vibrations," 1971.

[14] Pollution Control Department, Vibration measurement guide to prevent impact on buildings, Air and Noise Quality Management. Noise and Vibration Division, ed., Bangkok: He's company limited, 2021. [Online]. Available: https://www.pcd.go.th/publication/13881.

[15] D. Beben, T. Maleska, P. Bobra, J. Duda, and W. Anigacz, "Influence of Traffic-Induced Vibrations on Humans and Residential Building—A Case Study," International Journal of Environmental Research and Public Health, vol. 19, no. 9, p. 5441, 2022, doi: 10.3390/ijerph19095441.

[16] L. Ducarne, D. Ainalis, and G. Kouroussis, "Ground vibration generated by the passing of a truck on a speed bump," in 6th International Conference on Computational Methods in Structural Dynamics and Earthquake Engineering, Rhodes, 2017.

[17] A. Jakubczyk-Galczynska and R. Jankowski, "Traffic-induced vibrations. The impact on buildings and people," in Environmental Engineering. Proceedings of the International Conference on Environmental Engineering. ICEE, 2014, vol. 9: Vilnius Gediminas Technical University, Department of Construction Economics, p. 1.

[18] G. Watts, "Traffic induced vibrations in buildings," 0266-7045, 1990.

[19] M. B. M. Fozi et al., "Ground vibration analysis at speed humps for heavy vehicle: A case study in Batu Pahat, Johor," Journal of Safety, Health & Ergonomics, vol. 1, no. 2, 2019.

[20] D. Ainalis, L. Ducarne, O. Kaufmann, J.-P. Tshibangu, O. Verlinden, and G. Kouroussis, "Improved analysis of ground vibrations produced by man-made sources," Science of the Total Environment, vol. 616, pp. 517-530, 2018.

[21] C. Sacramento, "TRANSPORTATION RELATED EARTHBORNE VIBRATIONS," 2002.