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Investigation and Evaluation of Speed Table Influence on Road Traffic Induced Ground Borne Vibration

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Abstract. Vertical Speed Control Measures are vertical elevated segments of roadway that require a vehicle to slow. Typical vertical speed control measures include speed humps, speed tables, raised sidewalks and raised intersections. These engineering measures are used to reduce risk to pedestrians of crossing streets where transport flow is big. The object of this research is speed table. Measurements of ground borne vibration was done 1 m near the speed table and in reference point, in the same street where the speed table do not influence the traffic speed. Reference measurement point is in the same distance to the street as to the speed table. Measurements was done in two seasons: cold and warm. Ground borne vibration measurements took place in L. Asanavičiūtės st., Vilnius. In this research was found that highest acceleration value near the speed table was 21,8 mm/s^2 when heavy weight vehicles was passing, in reference point highest value was 38,1 mm/s^2. Heavy weight vehicles induce highest ground borne vibration peaks.

Keywords: Speed table, Ground borne vibration, traffic calming, traffic induced vibration.

Conference topic: Environmental protection.

Introduction

Traffic calming is the combination of mainly physical measures that reduce the negative effects of motor vehicle use, alter driver behaviour and improve conditions for non-motorized street users (Lockwood 1997).

It is indicated that traffic calming could mean anything from lowering speeds to an all-encompassing transportation policy.

To decrease the speed of vehicles in urban conditions, various types of road bumps can be used.

These measures require the vehicle to slow before the bump and usually its speed increases after the bump, adding an accelerating engine to the noise sources (Elioy, Vogiatzis 2012).

Vertical Speed Control Measures are vertical elevated segments of roadway that require a vehicle to slow. Typical vertical speed control measures include speed humps, speed tables, raised sidewalks and raised intersections.

Traffic calming measures can be implemented whenever the authority with jurisdiction over the road or street believes that they are necessary and appropriate to the situation. This can be on roads under municipal jurisdiction. However, the function and design of vertical traffic calming measures makes them more appropriate for relatively low speed roads than for roads with higher speed limits. Since the majority of highways typically carry traffic moving at speeds over 50 kilometres per hour, they are not usually considered appropriate for highways. But municipalities have many more residential style streets for which they may be useful as way of further calming traffic (Fazzalaro 2006).

Ground-borne vibrations are produced when vehicles pass over these profiles and in some cases they can reach perceptible levels in adjacent buildings. G. R. Watts and V. V. Krylov took measurements of peak particle velocity alongside a selection of hump and cushion designs using a range of vehicles under controlled driving conditions. Ground-borne vibrations are generally perceptible in situations where the road surface is uneven and buildings are situated close to the road. (Watts, Krylov 2000).

When a bus or a truck strikes an irregularity in the road surface, it generates an impact load and an oscillating load due to the subsequent "axle hop" of the vehicle. The impact load generates ground vibrations that are predominant at the natural vibration frequencies of the soil whereas the axle hop generates vibrations at the hop frequency (a characteristic of the vehicle's suspension system) (Hunaidi 2000; Lak *et al.* 2001). If the natural frequencies of the soil coincide with any of the natural frequencies of the building structure or its components, resonance occurs and vibrations will be amplified (Hajek *et al.* 2006).

The propagation of traffic-induced vibration from the source depends on the distance from the receiver, frequency of vibration, topography between the source and the receiver, and on the soil and other geotechnical characteristics of the ground. Vibration propagates through the ground in the form of body waves (compression and shear waves), and in the form of surface or Rayleigh waves (Fig. 1) (Hajek *et al.* 2006; Kramer 1996; Massarsch 2000).

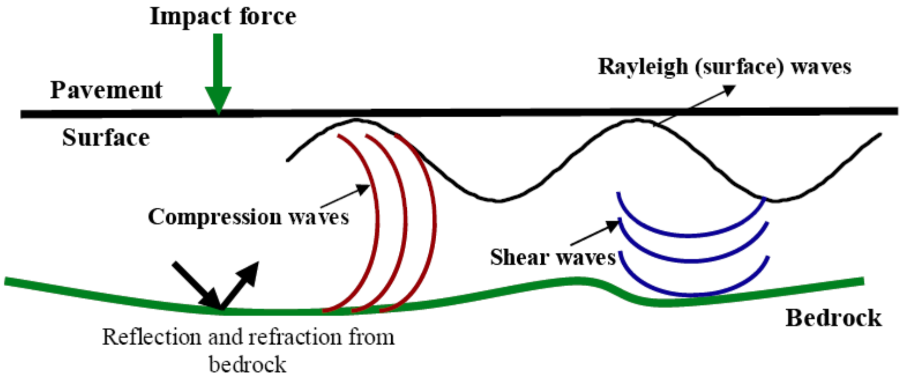


Fig. 1. Propagation of ground borne vibration (Hajek *et al*. 2006)

The Rayleigh waves are the most important form for the propagation of traffic induced vibration because at the ground level the amplitude of the Rayleigh waves decreases (due to geometric spreading) as the inverse of the square root of the distance from the source, while the amplitude of body waves decrease as the inverse of the square of the distance from the source (Hajek *et al*. 2006; Aster 2011; Bormann *et al.* 2012). The wave propagation of ground borne vibration when road traffic hits road unevenness is shown in Figure 1.

In this research speed table influence on traffic induced vibrations is investigated. The aim of this research is to evaluate the impact of the speed table due to concerns of ground borne vibration.

Method

Measurement

Measurements was taken in two seasons winter and summer season. According the same methodology to evaluate freezing influence on the traffic vibrations.

Distance from buildings to vertical traffic calming measure, relief, pavement ground structure, area building environment is being taken into account when selecting measuring points.

Measurement method was adopted and modified from Lithuanian hygiene norm HN 50:2003. To measure traffic induced vibration is used sound level and vibration meter Bruel&Kjaer Mediator 2260. In the set of equipment 3–axis accelerometer Delta Tron 4506 and amplifier 3-channel Human Vibration Front-end – Type 1700 is also used. Set of equipment used for vibration measurement is shown in Figure 2. The use of equipment in field measurements shown in Figure 3.

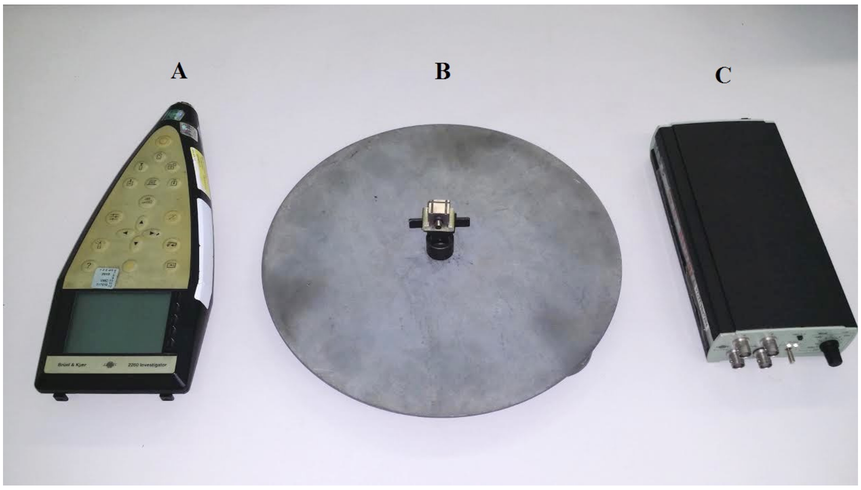


Fig. 2. Set of equipment used for vibration measurement: A – Sound level and vibration meter Bruel&Kjaer Mediator 2260; B – Steel plate with 3–axis accelerometer Delta Tron 4506; C – amplifier 3-channel Human Vibration Front-end – Type 1700 (author's picture)

Acceleration of the vibration is being measured in all three axis (X, Y, Z). After the check, measurements are taken in that axis in which acceleration of the vibration is highest. Z axis is vertical axis, X axis parallel to the road, y axis crossing the road. Measuring parameter is acceleration of vibrations (mm/s^2).

Fig. 3. Steel plate and accelerometer use in field measurement (author's picture)

Every vehicle crossing the vertical traffic calming measure was measured separately. Vehicles are separated into 3 categories:

1. Light vehicles (Light passenger vehicles)
2. Moderate weight vehicles (Light cargo or light passenger vehicle with trailer)
3. Heavy weight vehicles (Buses or heavy cargo vehicles)

Measuring parameters are: Acceleration of the vibration in 1/3 octave band; Measurement units (mm/s^2); Measuring in frequencies from 6.3 Hz to 3150 Hz.

The selected measurement points representing vibration acceleration near the speed table and without it. The measurements were taken 1 m distance to the speed table and 10 m further to evaluate the propagation of the ground borne vibration near the speed table. Other two measurement points selected in area of the same street where the speed table do not influence the traffic induced ground borne vibrations.

Data processing

Huge amount of data was received after measurements. In every octave band trimean is being calculated. This characteristic is not "sensitive" to extreme values, trimean is used in asymmetric value distribution (Čekanavičius, Murauskas 2000).

$$Trimean = \frac{Q_1 + 2Md + Q_3}{4}, \tag{1}$$

where: Md – median; Q_1 – First quartile; Q_3 – Third quartile.

In descriptive statistics, the quartiles of a ranked set of data values are the three points that divide the data set into four equal groups, each group comprising a quarter of the data. A quartile is a type of quantile. The first quartile (Q_1) is defined as the middle number between the smallest number and the median of the data set. The second quartile (Q_2) is the median of the data. Median is the number separating the higher half of a data sample, a population, or a probability distribution, from the lower half. The third quartile (Q_3) is the middle value between the median and the highest value of the data set.

Observational error (or measurement error) is the difference between a measured value of quantity and its true value. In statistics, an error is not a "mistake". Variability is an inherent part of things being measured and of the measurement process.

Root mean square error (RMSE) is a frequently used measure of the differences between values (sample and population values) predicted by a model or an estimator and the values actually observed.

$$S_{\overline{x}} = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \overline{x})^2}{n(n-1)}}, \tag{2}$$

where: Sx – root mean square error; X_i – measured value; $\overline{x}$ – Arithmetic mean; n – number of observations.

In mathematics and statistics, the arithmetic mean, or simply the mean or average when the context is clear, is the sum of a collection of numbers divided by the number of numbers in the collection.

$$\overline{x_n} = \frac{1}{n}\sum_{i=1}^{n} x_i\ ,, \tag{3}$$

where: $\overline{X_n}$ – arithmetic mean; n – number of observations; X_i – measurement value.

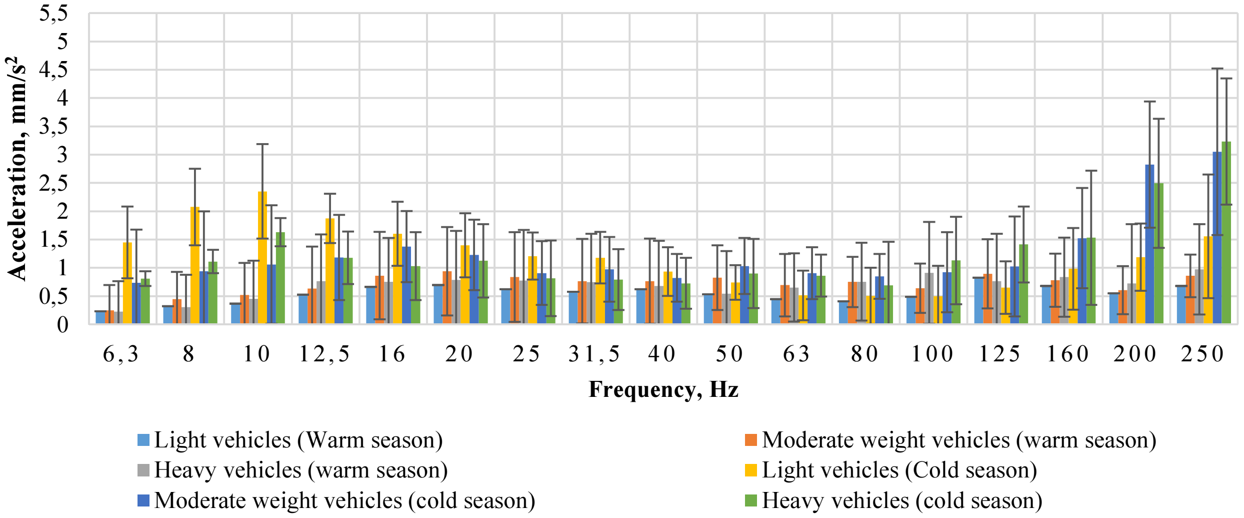
All ground borne vibration measurement data and error is presented using this methodology.

Results

The number of vehicles measured differs in between two seasons cold (winter) and warm (Summer). During the cold season measurements air temperature was – 5.6 °C, wind speed 1,2 m/s, humidity 78,4, atmosphere pressure 99.8 kPa. During the warm season measurements air temperature was 18 °C, wind speed 1.1 m/s, humidity 61%, atmosphere pressure 100.4 kPa. Presented vibration acceleration data is in Z axis, because values found highest in this axis.

Table 1. Number of vehicles passed during measurements

Measurement site	No. of vehicles passed					
	Cold season			Warm season		
	Light vehicles	Moderate weight vehicles	Heavy vehicles	Light vehicles	Moderate weight vehicles	Heavy vehicles
1 m near speed table	15	9	4	15	14	6
1 m reference point	15	9	4	15	11	5



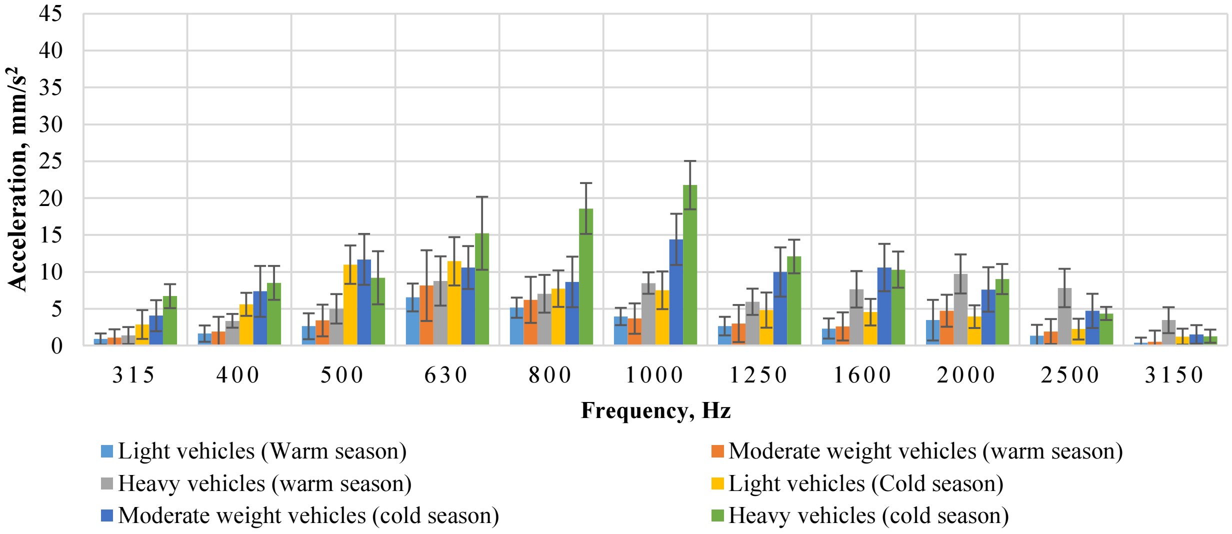


Fig. 4. Results at measurement site 1 m distance to the speed table, during cold and warm season

In measurement site one meter distance (cold season) to the traffic calming measure, highest vibrations acceleration was found in 1000 Hz and 630 Hz frequencies (light vehicles 11,5 mm/s^2 at 630 Hz, moderate weight vehicles 14,4 mm/s^2 at 1000 Hz, heavyweight vehicles 21,8 mm/s^2 at 1000 Hz). During measurement was noticed that light and moderate weight vehicles when passing speed table reduced their speed less than heavyweight vehicles. But still heavy weight vehicles induces highest vibrations at this measurement point.

The same vibration measurements was done during the warm season in summer time. In measurement point one meter distance to the traffic calming measure, highest vibrations acceleration was found in 630 Hz frequency (light vehicles 6,5 mm/s^2 at 630 Hz, moderate weight vehicles 8,2 mm/s^2 at 630 Hz, heavyweight vehicles 8,2 mm/s^2 at 630 Hz). During measurement was noticed that light and moderate weight vehicles when passing speed table reduced their speed less than heavyweight vehicles. But still heavy weight vehicles induces highest vibrations at this measurement point. Graph of results is shown in Figure 4.

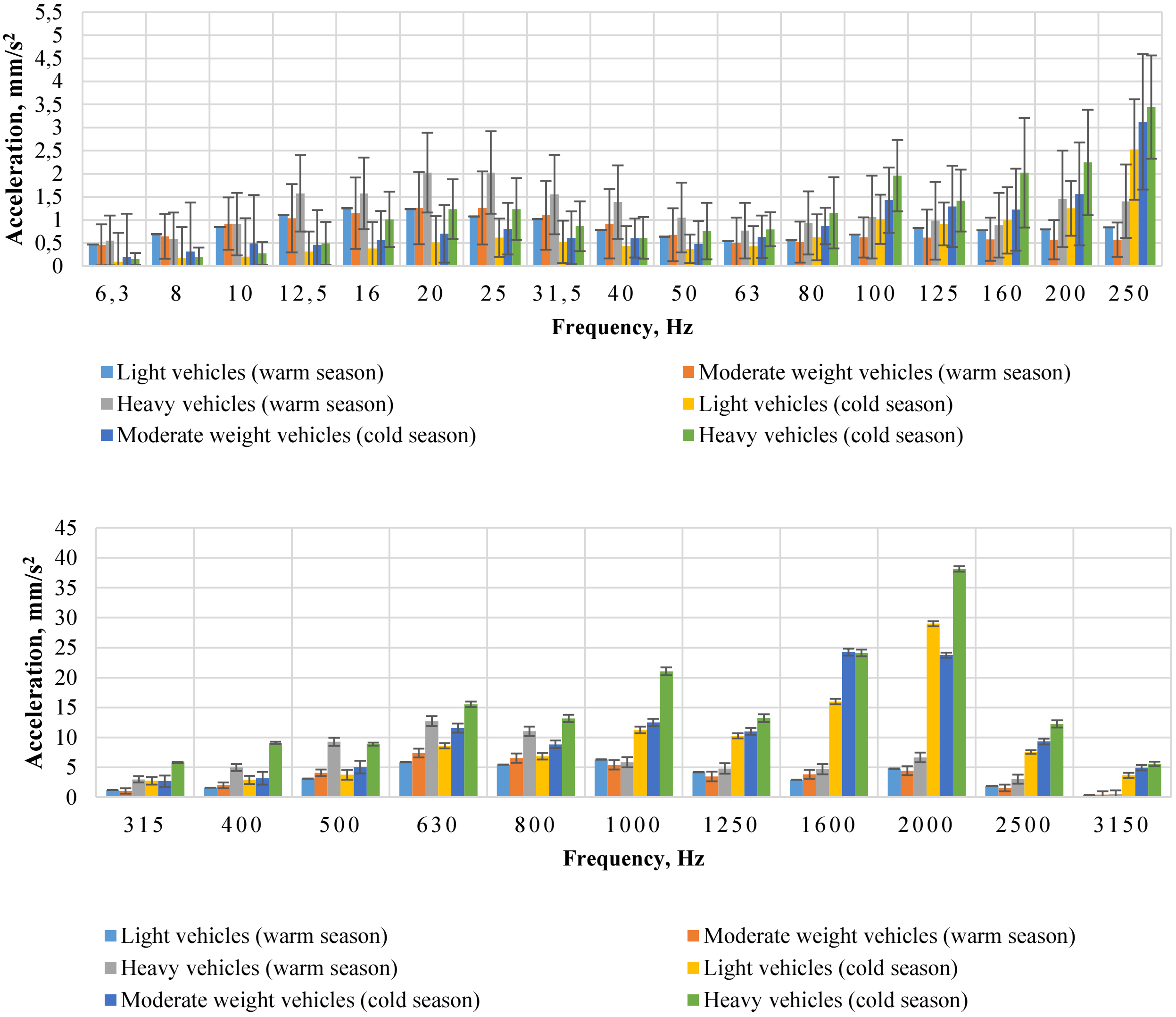


Fig. 5. Results at reference measurement point, during cold and warm season

Acceleration of the vibration was measured in reference point 1 m from L. Asanavičiūtė Street where vertical traffic calming measure has no impact on the traffic induced vibrations during the cold season. Highest vibrations acceleration was found at 2000 and 1600 Hz frequencies (light vehicles 29,0 mm/s^2 at 2000 Hz, moderate weight vehicles 24,8 mm/s^2 at 1600 Hz, heavyweight vehicles 38,1 mm/s^2 at 2000 Hz).

During the warm season, highest vibrations acceleration was found at 630 Hz frequency (light vehicles 5,9 mm/s^2, moderate weight vehicles 7,4 mm/s^2, heavyweight vehicles 12,8 mm/s^2). Graph of results is shown in Figure 5.

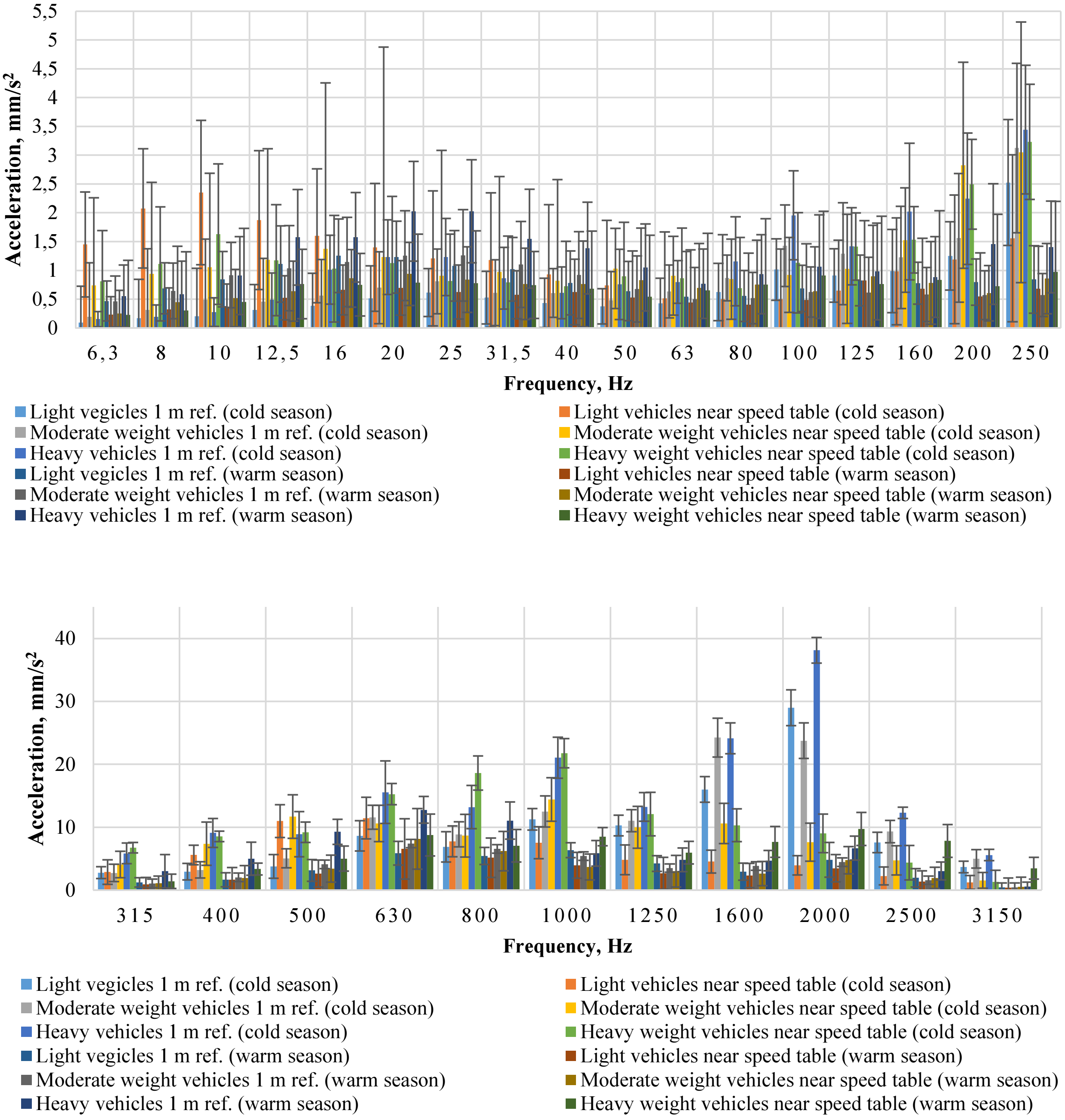


Fig. 6. Comparison of results, between measurement point near the speed table and reference point

During the cold season (Fig. 6) when light vehicles was passing measurement results show that at lower frequencies (6,3–63 Hz) higher values of vibration is near the speed table, but in higher frequencies vibrations higher in reference point. When moderate weight vehicles was passing at the most frequencies (6,3–500 Hz and 630–1000 Hz) higher values of vibration is near the speed table, but in higher frequencies vibrations higher in reference point. The peak of acceleration gained near in reference point is 58% higher than near the speed table. When heavy weight vehicles was passing results show that at the most frequencies (6.3–500 Hz and 630–1000 Hz) higher values of vibration is near the speed table, but in higher frequencies vibrations higher in reference point. The peak of acceleration gained near in reference point is much higher than near the speed table.

During the warm season (Fig. 6), when light vehicles was passing gained results show that at the most frequencies (except 630 Hz) higher values of vibration is at the reference point. The peak of acceleration gained near in reference point is higher than near the speed table. The peak acceleration found near the speed table reached 6.6 mm/s^2. When moderate weight vehicles was passing vibration acceleration values at the most frequencies (except 630 Hz) found higher in the reference point. The peak of acceleration gained near in reference point is higher than near the speed table. In the Figure 6 is shown comparison of results gained in different measurement sites. Results show that at the most frequencies (except 1000–3150 Hz) higher values of vibration is at the reference point. The peak of acceleration gained near in reference point is higher than near the speed table. Highest peak of acceleration was found at 630 Hz in reference point, value reached 12.8 mm/s^2.

Summary and discussion

The measurements was done in real traffic conditions. Every vehicle passes with different speed which is unknown. The vehicle suspension stiffness is also unknown.

Higher vibration acceleration was found during cold season, highest peak value reached 38.1 mm/s^2 when heavy vehicles was passing through the reference measurement point. During warm season highest peak of acceleration was found also in the reference point when heavy vehicles was passing, the value reached to 12.75 mm/s^2.

Heavy vehicles induce higher vibrations than other categories of transport. Even though it was noticed that visually noticed that heavy vehicles passed measurement site slower than other two categories of transport, light and moderate weight vehicles induce smaller acceleration of vibrations than heavy transport. When light and moderate weight vehicles mass is similar 1.5–3.5 t, heavy vehicles is much heavier typical heavy vehicle weights around 18 t (Kansas, 2012) based on assumption that most of heavy transport was garbage trucks and busses. This difference of weight let heavy vehicles induce higher vibration acceleration than other two types of transport.

The difference of vibration acceleration between the reference point and measurement point near the speed table indicates that speed table influence on traffic induced vibration is low or it's lowering the vibrations. However street pavement is uneven and repaired several times. Also the huge factor is the vehicle speed, visually the vehicles passes speed table at relatively low speed and runs faster through the reference measurement point.

Conclusions

- Higher vibration acceleration was found during cold season, highest peak value reached 38,1 mm/s^2 when heavy vehicles was passing.
- Heavy vehicles induce higher vibrations than other categories of transport. The peak value registered when heavy vehicles was passing reached 38,1 mm/s^2, light and moderate weight vehicles induced vibrations reached 29,0 mm/s^2 and 24,3 mm/s^2 respectively.
- Speed table reduces ground borne vibrations in L. Asanaviciute str. Vehicles passing the speed table reduces speed enough to induce lower values of vibration acceleration. Highest acceleration value found near the speed table was 21,8 mm/s^2 when heavy weight vehicles was passing, in reference point highest value was 38,1 mm/s^2.

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