SUSTAINABLE DEVELOPMENT OF CITIES: EFFECTS OF TRAFFIC INDUCED VIBRATION ON HUMANS

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Abstract

Traffic induced vibrations can hardly cause the damages of buildings but can caused the disturbances and annoying affects of their occupants. This phenomenon has been the object of investigations in many countries due to the rapid urbanization of the modern cities and due to the demand of sustainable development. In this paper presented is the assessment of vibrations on humans in buildings caused by the traffic in Belgrade, Serbia. Due to the luck of national standard for evaluation of effects of vibrations on humans, the German standard DIN 4150-Part 2 was implemented. The results of evaluations are presented and discussed.

Keywords: *sustainable development, traffic induced vibration, effects on humans in buildings, signal processing*

1. INTRODUCTION

Since 1982, when The World Commission on Environment and Development was initiated by the General Assembly of the United Nations, the sustainable development has been presented as the continued improvement of the quality of life. The Commission

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This paper was presented at the international conference "Innovation as a Function of Engineering Development" - IDE 2011

chairmen then–Prime Minister of Norway Gro Harlem Brundtland defined the sustainable development as ”development that meets the needs of the present without compromising the ability of future generations to meet their own needs” [12]. The so-called Brundtland Commission began its work committed to the unity of environment and development. In the interim, sustainable development as a concept, as a goal, and as a movement spread rapidly. Ten years latter it was accepted by all national leaders at the Earth Summit in Rio de Janeiro (1992). The goal of idea is to ensure a better quality of life for all now and for generations to come. Achieving this goal requires the comprehension of three interdependent parts: environmental, economic and social.

Concerning the construction engineering, priorities of sustainable development are [9]:

• A transport system that minimizes environmental harm and reduces annoying effects on civilian.

• Towns and cities that are better places to live and work.

In the last years, traffic induced vibrations has been seriously investigated in many countries due to the rapid development of the urban transportations and its annoying effects on the citizen. In many countries have been adopted the standards concerning the effects of vibrations on buildings and humans (USA, Germany, Great Britain, Japan, Norway, etc.). In Serbia there are luck of standards and systematical investigation in this field. Investigation presented in this paper show that traffic induced vibrations measured along one of the main boulevard in Belgrade are above the threshold value concerning the effects on humans in buildings according to the German standard DIN 4150-Part 2. In order to provide sustainable development of the city, further investigations and adoption of some standard is inevitable demand.

2. CHARACTERISTIC OF VIBRATIONS

Traffic vibrations are mainly caused by heavy vehicles such as buses, trucks and trams, while passenger car rarely produce vibrations. These vibrations are transferred through the ground to the foundation where they are amplified at the building structures and affect their occupants.

The predominant frequencies and amplitude of the vibrations depend on many factors: the condition of the road, vehicle weight, speed and suspension system, soil type and stratification, type of building and distance from the road. Generally, the rougher the road, the more speed affects the vibration amplitude; the lower the stiffness and damping of the soil, the higher the vibration. Investigations have shown that road traffic produces vibrations with frequencies predominantly in the range from 5 to 25 Hz, while the amplitudes of vibration lay in the range of 0.05 and 25 mm/s, measured as velocity, or 0.005-2 mm/s2 measured as acceleration.
Intensity and frequency of traffic induced vibrations depend on the following factors:

- source of vibrations (tram, bus, cars, etc.),
- road roughness,
- distance from the road,
- tupe of structures and ceillings,
- soil characteristics and foundations.

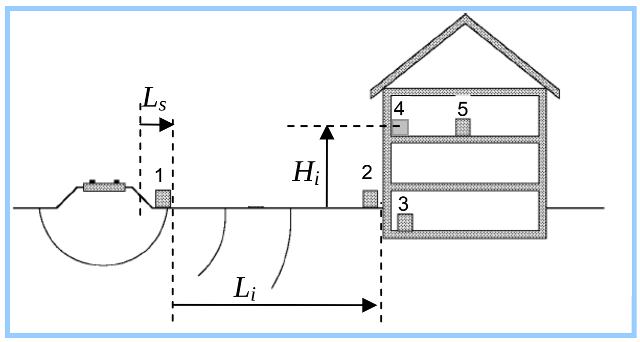
The frequency content of vibrations depends on: type of vehicle suspension system, vehicle weight and velocity. In general, higher the roughness of the road and vehicle speed, higher the amplitude of vibrations; less the stiffness and material damping of the soil, higher the amplitude of vibrations. In the case of the soft soil layer 7-15 m deep, the effect of resonance between the natural frequencies of soil layer and building can cause the significant amplification of vibrations.

Numerous investigations and measurements of vibrations, [2], [5], [6], [10] have shown that traffic-induced vibrations rarely cause damage of the structures, but can cause annoyance of building residents, as well as normal functioning of sensitive equipment.

3. FIELD TEST AND MEASUREMENTS

The vibrations were measured on 24 buildings along the street Bulevar kralja Aleksandra in Belgrade [10], [11]. The measurements were carried out by Geophysical Institute, using I/O System One that consists of 5 three-component geophones. The velocities were measured simultaneously at five different points at the building site,

Fig. 1, in three orthogonal directions: vertical - V, horizontal, parallel to the road - H1 and horizontal, perpendicular to the road - H2.



- point 1 - on the sidewalk about 1m from the road,
- point 2 – on the ground at the external foundation wall,
- point 3 – in the basement of building close to the external wall,
- point 4 – at the top floor by the wall,
- point 5 – at the top floor at the centre of the room floor.

Fig. 1. Measurement points

Vibrations were measured due to the following sources:

- ambient sources,
- truck, weighted approximately 14 tons at speed 50 km/h,
- truck: 14 tons, speed 50 km/h, across the rubber ramp 40 cm long and 3 cm high,
- articulated bus or tram.

Higher vibration levels were obtained for vertical direction than for two horizontal directions. Therefore, the assessment of vertical vibrations has been calculated and presented.

4. EFFECTS ON HUMANS

Traffic induced vibrations may be unacceptable to humans in buildings because of the annoying physical sensations and noise.

The International Organization for Standardization and several countries have published standards (ISO 2631-1, ISO 2631-2, DIN 4150-2, BS 6472, etc.) that provide guidance for evaluation of human response to continuous, intermittent, and transient vibrations in buildings [1], [3], [7], [8]. The basic quantity used for analysis of vibrations is either the particle acceleration *a(t)* or particle velocity time history *v(t).*

The guidance provided by the ISO 2631 standard, Part 1 and 2, [7], [8] for evaluation of the effects of traffic induced vibrations on humans in buildings is based on measured accelerations. There are three major difficulties in applying this standard. Firstly, there was confusion regarding the classification of vibrations, as intermittent or transient ones. Secondly, the vibration levels are provided in terms of one second acceleration rms (root-mean-square) values, which is not quite applicable to short-time vibrations. Also, the acceptable magnitudes of vibrations are not stated in the report. Therefore, in order to evaluate the effects of vibration on humans the German Standard DIN 4150: Part 2 [3] was used in our investigations.

4.1. DIN 4150-Part 2

The ability of humans to perceive vibration is directly proportional to vibration velocity over most of the frequency range. Due to that, the basic quantity used for analysis of vibrations in DIN 4150 is particle velocity time history *v(t)*. In DIN 45669-Part 1 [4] the assessment of impact of vibrations on humans is based on the maximum weighted vibration severity $KB_{Fmax}=max[KB_{F(t)}]$, where $KB_F(t)$ is running rms (root-mean-square) of weighted signal *KB(t):*

$$KB_F(t) = \sqrt{\frac{1}{\tau}\int_{\xi=0}^{t} e^{-\frac{t-\xi}{\tau}} KB^2(\xi)d\xi} \,. \tag{1}$$

In Eq. (1) τ is the time constant, equal 0.125 s, ξ is the integration variable and $KB(\xi)$ is weighted and normalized velocity signal.

In order to obtain *KB(t)*, the unweighed velocity signal *v(t)* should be first filtered using high pass and low pass 2-pole filter with Butterworth characteristic (the high pass frequency is 0.8 Hz and low pass frequency is 100 Hz). The bandlimiting filter function is given by complex transfer function:

$$H_{unom}(if) = \frac{1}{\left[1 - i\sqrt{2}\,\frac{0.8Hz}{f} - \left(\frac{0.8Hz}{f}\right)^2\right]\left[1 + i\sqrt{2}\,\frac{0.8Hz}{f_{\max}} - \left(\frac{0.8Hz}{f_{\max}}\right)^2\right]} \tag{2}$$

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where f_{max}=80 Hz. Then the filtered velocity signal should be frequency weighted using frequency weighted complex function, shown in **Error! Reference source not found.**.

$$H_{Bnom}(if) = \frac{1}{1 - i\frac{5.6Hz}{f}} \tag{3}$$

where f is frequency in Hz, and $i^2=-1$.

This calculation could be done in frequency domain or in time domain using the signal processing. In this work the program Matlab signal processing toolbox was used to calculate appropriate filters and *KB(f)*. In Fig. 2 and 3 presented are *KB(t)* and $KB_F(t)$ for vibrations at the top floor of a building induced by tram and truck, respectively.

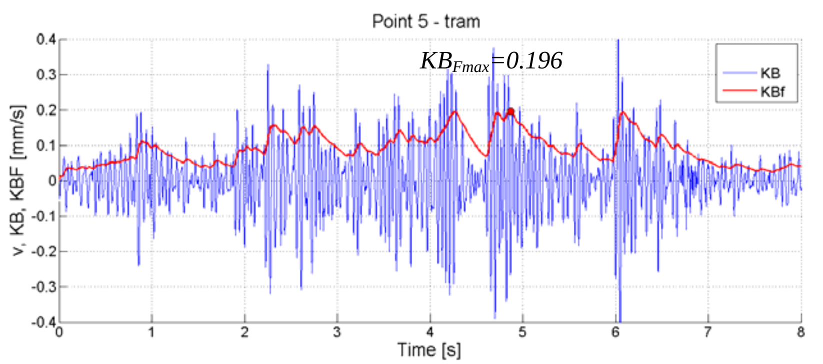

Fig. 2 KB(t) and $KB_F(t)$ caused by tram

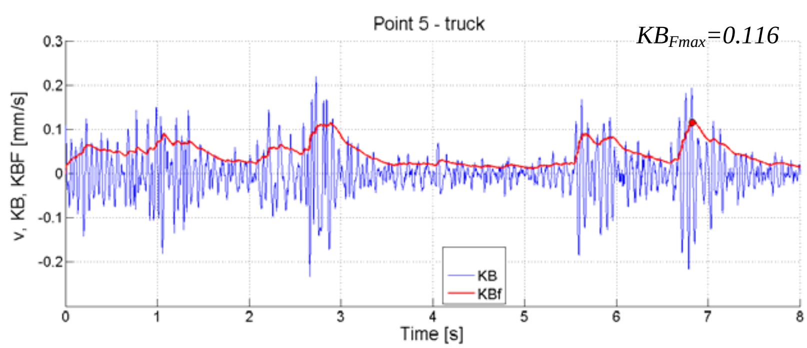

Fig. 3 KB(t) and $KB_F(t)$ caused by truck

For a single event the vibration severity $KB_{f,max}$ was compared with the thresholds given in DIN 4150-2, Table 1.

Table 1 Threshold for assessment of the effect of induced vibrations on human comfort

Vibration exposure location	Day			Night		
	A_u	A_o	A_r	A_u	A_o	A_r
Commercial facilities only	0.4	6	0.2	0.3	0.6	0.15
Mainly commercial facilities	0.3	6	0.15	0.2	0.4	0.10
Mixed area	0.2	5	0.1	0.15	0.3	0.07
Mainly residential houses	0.15	3	0.07	0.1	0.2	0.05
Sensitive area, e.g. hospitals	0.1	3	0.05	0.1	0.15	0.05

If $KB_{fmax} \leq A_u$ then the requirements of this norm is satisfied – vibration is less than threshold value. If $KB_{fmax} \geq A_o$ then the requirements of this norm is not satisfied, and some measure for reduction of vibrations should be taken. For frequent excitations, when $A_u \leq KB_{fmax} \leq A_o$ a further step is required. KB_{FTm} has to be calculated according to Eq. (3) and compared with A_r.

$$KB_{FTr} = KB_{FTm}\sqrt{\frac{T_e}{T_r}}, \qquad KB_{FTm} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} KB_{FTi}} \,. \tag{3}$$

In Eq. 4 T_e is duration of exposure, T_r is the period of assessment (16 h for day time and 8 h for night time), while KB_{FTi} is max $KB_F(t)$ in one tact T_i=*30 sec*, *i=1,..N*, Fig. 4.

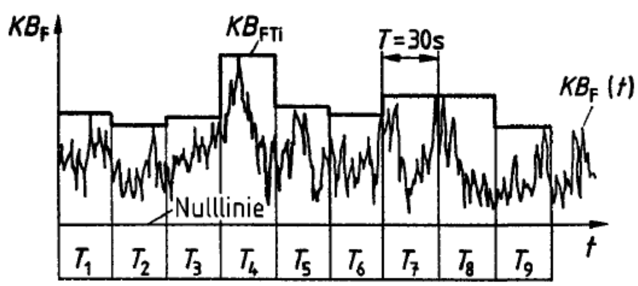

Fig. 4 KB_{FTi}

Since, only single events were measured, the KB_{fmax} was calculated for all vibration sources and compared with A_u. Due to the luck of space, the KB_{fmax} for low-, mid- and high-rise buildings are presented for the cases of most intensive vibrations induced by tram and truck over ramp in Fig. 5 and 6. The low-rise buildings are buildings between 1-3 floors, mid-rise are buildings between 3-7 floors and high-rise are buildings higher than 7 floors.

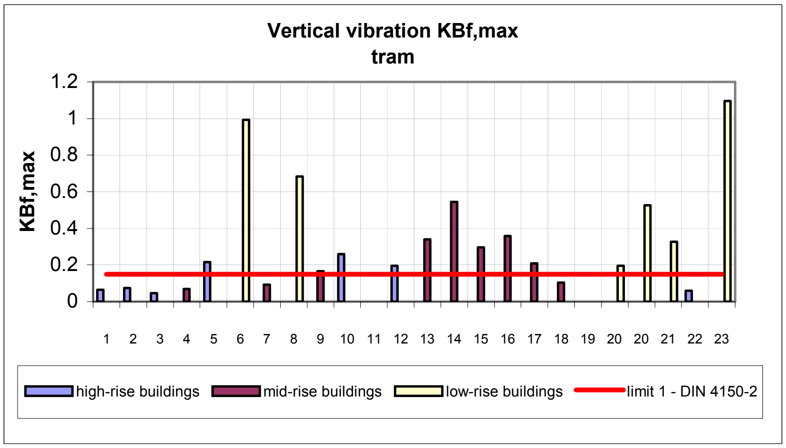

Fig. 5 KB_{fmax} of vertical vibrations at the top floor due to the tram passage

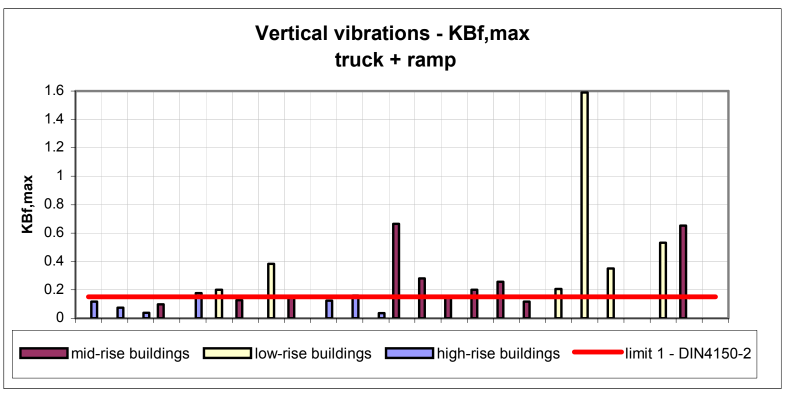

Fig. 6 KB_{fmax} of vertical vibrations at the top floor due to the truck over ramp

KB_{fmax} for tram induced vibrations exceeds the limit value A_u, in all low-rise buildings and in 2/3 of mid-rise buildings, whence only 2 from 7 high rise buildings were affected. KB_{fmax} for vibrations induced by truck over ramp exceeds the limit value A_u, in all low-rise buildings and in 7 from 9 mid-rise buildings, whence only 2 from 7 high rise buildings were affected.

5. CONCLUSION

During the measurements of 24 buildings along the Bulevar kralja Aleksandra in Belgrade a large amount of data was collected and evaluated (more than 1500). The effect of vertical vibrations on humans in buildings was assessed according to DIN 4150-2. Comparing the vibration severity with the threshold values given in DIN 4150-2 concluded was the following:

- maximum vertical vibrations in buildings are obtained due to the truck crossing the ramp and tram,
- the predominant frequencies of vertical vibrations are in the range from 5 to 25 Hz,
- low-rise and mid-rise buildings are more sensitive to traffic induced vibrations, while high-rise buildings are less sensitive.

This indicates that traffic-induced vibrations impact significantly the quality of life in the centre of Belgrade, so the effects of the future metro line on the humans in buildings along the Bulevar kralja Aleksandra Street should be carefully analyzed. The obtained data can be used for making the program of further measurements and assessment of vibrations as well as to make prediction model to evaluate the vibration levels of the buildings influenced by the prospective traffic, in the sense of the sustainable development of the city.

ACKNOWLEDGEMENT

This research is financially supported through the project TR 36046 by the Ministry of Science and Technology, Republic of Serbia.

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