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A CASE STUDY ON INFLUENCE OF TRAFFIC-INDUCED VIBRATIONS ON BUILDINGS AND RESIDENTS

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Abstract: Vibrations induced by traffic on irregular or damaged pavement or tracks positioned near buildings, can be a source of annoyance for residents and source of damage to structural and non-structural elements. The traffic-induced vibrations, having different frequency content, propagate through the soil towards neighbouring buildings while attenuating in the process due to damping. However, when vibrations reach the basement wall or foundation of the building they are transmitted to upper floors and can be amplified in the process depending on the eigen frequencies of the building components. In this work, described is the procedure for experimental determination of the vibration measurement in comparison with the values allowed by the code provisions. Additionally an overview of the building damage due to traffic induced vibrations is given including the unavoidable description of the annoyance experienced by its residents.
Keywords: Damaged Roads, Damage To Building, Resident Annoyance, Traffic-Induced Vibrations

INTRODUCTION

Vibrations induced by traffic on irregular or damaged pavement or tracks positioned near buildings, can be a source of annoyance for residents and source of damage to structural and non-structural elements [1,2]. The traffic-induced vibrations, having different frequency content, propagate through the soil towards neighbouring buildings while attenuating in the process due to damping. However, when vibrations reach the basement wall or foundation of the building they are transmitted to upper floors and can be amplified in the process depending on the eigen frequencies of the building components (see Figure 1).

In this work elaborated is the case study on the influence of traffic-induced vibrations to buildings and residents that was a subject of a lawsuit [3,4].

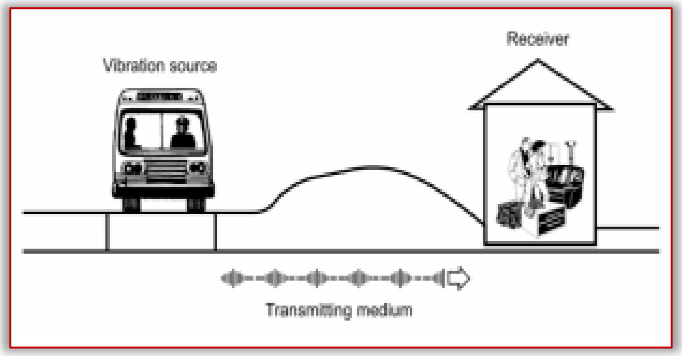

Figure 1. Path from vibration source to the building

During highway construction, the stone material used for the sub-grade and the sub-base of a future highway, was brought from a nearby quarry. The supply roads used to deliver the stone material to the construction site were partially the part of the main road system of the nearby small town. They were used over the period of three years. The traffic was intensive, having large number of trucks mostly loaded with crushed stone, passing towards the construction site and the way back. The quantity of the transported material usually had weight higher than by standards prescribed values. The traffic was ongoing whole day long, having usually the both road lanes occupied. Present was intensive breaking near the town crossroad and also unappropriated truck speed.

The town roads were deteriorated with bumps and holes even before the transport of building material started. The town buildings were positioned mostly very near the road. The town building stock consisted mostly of family houses built 50 or 20 years ago. The intensive material transport over town roads in poor condition had negative influence on them. They experienced slight or heavy damage in dependence on the building's age. Consequentially, present was the fear and uncertainty of the building owners due to possibility of the damage progression, vibrations and noise.

Soon after three years, the transport of the building material was shifted to another location as requested by the town residents. The roads were repaired by fixing the bumps and holes and introducing the new base, binder and surface courses. Afterwards, the eight building owners had initiated a lawsuit against road maintance company for negligence. They were seeking a compensation for building rehabilitation due to damage caused by vibrations due to intensive traffic and unmaintained road.

The task of the court specialist in this case was to provide evidence that the damage to buildings was caused by vibrations from increased traffic in the period of highway construction, to determine the damage level and its influence on the stability and serviceability of the buildings, and to provide recommendations on the possibilities of building rehabilitations or to suggest demolition.

In order to complete the task the visual inspection of the buildings was conducted in order to determine the size of the damage and to grade the condition of the building. Conducted was the reconstruction of the events suspected to be the cause of the current building condition. The aim was to measure and to envisage vibrations caused by intensive traffic in the period of highway construction in order to relate them with negative effects on buildings and residents.

BUILDING INSPECTION AND VIBRATION MEASUREMENT

— Building condition inspection

The visual inspection is the first to be conducted in the process of determination of the building's condition. If by visual inspection no damage was discovered, there is no need to conduct the further examinations. By visual inspection determined are locations on the structure with damage which is usually manifested through small or large cracks on e.g. foundation walls, load- and non-load bearing elements, ceilings, walls, roof, staircases, near openings, chimneys, plaster, etc.

By spotting and recording the crack locations, measured was their size and the overall building condition was assessed i.e. safe or unsafe for residents. The assessment of structural and non-structural damage and building overall condition was conducted based on comparison of measured data with the by standard prescribed values.

The procedure of damage record was conducted by using the table forms for in-situ building damage and condition assessment after an earthquake. Based on the conclusion on overall building condition, given were recommendations for building rehabilitation in order to bring them to serviceable condition.

The total number of eight buildings were examined, located in two streets where the intensive traffic was present. In all buildings spotted was damage in the form of cracks of different size and shape spread over the entire building. Mostly affected were the walls, foundations, foundation walls, floors, ceilings, near openings, balcony and ceramic tiles. Additionally, observed were settlements, roof tile movements, rain lea page, even the wall buckling and ceiling collapse.

All observed building damage could have been a consequence of other irregularities such as from e.g. building construction, poor building maintenance, poor water drainage and soil settlement. Therefore, in order to relate the consequences of intensive heavy traffic-induced vibrations, it was necessary to determine the intensity of vibrations.

— Traffic-induced vibrations measurement

By intensive three year traffic of loaded and unloaded trucks over the road in poor condition, the higher vibrations of the surrounding ground were constantly present. They consequently propagated towards nearby buildings.

The traffic intensity was about 150 trucks on daily basis which can be qualified as long-term and intensive action. The intensity of excitation transmitted through the ground to the building is a function of: source excitation intensity, distance from the source to the building, ground type (radiation damping), ground water level, road condition, building structural system, building material characteristics, etc. Transmitted vibrations activated the inertia forces causing deformations of foundation and afterwards the rest of the building.

The task of the specialist was to provide the evidence that the traffic load caused higher dynamic excitation on buildings and consequently their damage. In order to provide such an evidence it was necessary to measure the intensity of vibrations caused by traffic. As measurement location points selected were the ground near building foundations and the 1st storey in multistorey buildings.

By vibration measurement the general dynamic response of a building is determined (resonant frequencies, damping). The most important parameter governing the dynamic response is the building resonant frequency since in the case of coincidence with dynamic excitation frequency becomes a cause of significant increase in response amplitudes. The influence of vibrations to the building is two-way, it causes damage to the building and annoyance to residents [10,11].

Based on vibration measurements, assessed was the relationship between the traffic load and the damage in the building. This was done in way that measured vibration level was compared with the values allowed for the buildings and residents as prescribed by the corresponding standards [5-9]. The hardest was to determine what and how much did it happen. In order to answer these questions, it was necessary to reconstruct the events that occurred several year ago having many characteristics changed within the period. The reconstruction was conducted by using heavy truck passage in front of the observed building.

The road condition in the period of intensive traffic was different then on the day of measurement. It was renewed thus not having bumps, holes, depressions, etc. In order to simulate the road irregularities the wooden board 24 mm thick was place on the road. The aim was to produce the effect of truck passage over the hole in the road. In the reconstruction of events used was one truck, having average speed of 30 km/h, and loaded with 77 % of nominal value, which was in compliance with the standards for cargo transports. The respondents claimed that the load in the trucks during the material transport was much higher than nominal one, and that they were passing in train formation, or by passing each other while having inappropriate speed. Therefore, much of the input parameters differs from original situation: road condition, truck weight, truck speed, traffic frequency, etc.

All of the named quantities imply that the dynamic excitation was many times higher than the measured one. This bias was tried to be overcomed by multiplying the measured quantities by the factor of 2. Vibration measurement was not conducted on all eight buildings. Only four were selected that represent the existing diversity in the building stock (age, condition, and distance to road). The selected buildings are marked in Figure. 2 by black dots. Measured was the intensity of horizontal vibrations (in x- and y-direction) and vertical vibrations (z- direction), caused by truck loaded with 26640 kg (of possible 35000 kg) of material. The total truck mass was 41240 kg. The truck passage was repeated several times.

For the purpose of vibration measurement used were instruments of "Syscom Instruments AG" company (see Figure 3 and 4). Instruments were specially devised for civil engineering purposes, and used in buildings, tunnels, construction sites, etc. Measuring system is recording the response velocities and the date are recorded to computer.

Veleocymeters are used to measure the response in the three different directions simultaneously (x-, y- and z-direction). Total measurement time was 5 h.

Figure 2. Map with supply truck routes and damaged buildings

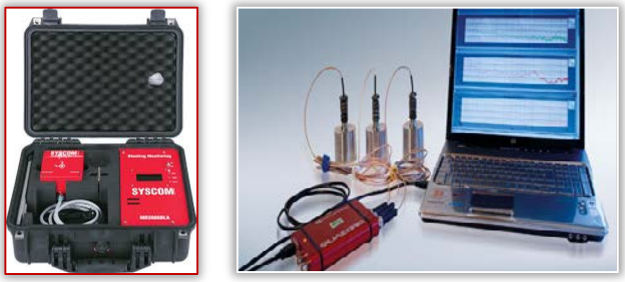

Figure 3. View on the measuring equipment

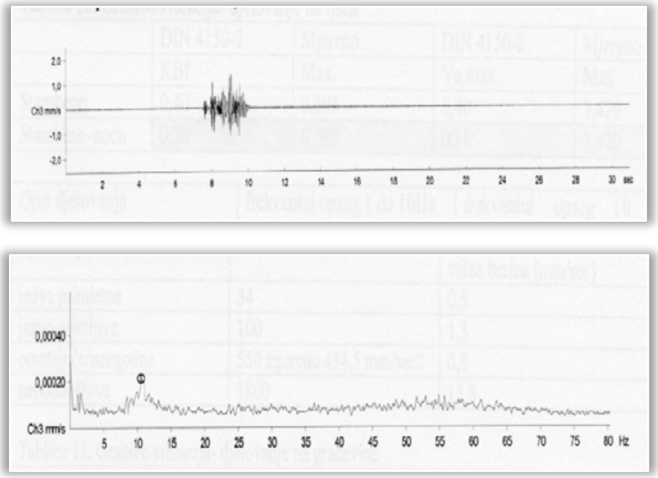

Figure 4. Time history record of vertical velocities (in mm/sec) at foundation (above) and acceleration data (in mm/sec^2) at various frequencies

VIBRATION MEASUREMENT RESULTS

Presented are results for single building that suffered the most of the damage (see Figure 5). The building is a house with basement of dimensions 80 m^2, built in two parts (50 and 30 m^2) with solid brick masonry without confining elements. The first, old part, was built 60 years ago, and second part was built several years ago. Due to age it is considered as sensitive building. The building is placed near road with 7 m distance to its closest point, and 19 m to its farthest. The foundation soil is rock. The building experienced both, the structural (collapse of storey slab in older part, cracks in outer and foundation wall) and the non-structural damage (cracking of windows, cracked ceramic tiles, displacement of roof tiles and rain water leakage).

Figure 5. Damage to the ceiling (left) and damage to the ceramic tiles (right)

To answer the question whether the traffic-induced vibrations caused the named building damage, measured quantities were compared to quantities prescribed by following standards: SN 64031a, DIN 4150 and ISO 2631 (see Tables 1 to 3).

The resonant frequencies of the building with structural masonry walls are usually similar for longitudinal and transversal direction, even when the ground plan aspect ratio is 3 to 4. The first vibration period of the structure can be estimated based on expression $T_1=0.0165*H$ ($f_1=1/T$), which applied to the observed building comes to $T_1=0{,}084$ sec ($f_1=11.9$ Hz) in both directions.

Vibrations besides that they cause annoyance to residents, they disrupt working ability and long-term their health. In case observed, vibrations were disrupting the residents during the days, and were unbearable during night.

The increased traffic, and correspondingly the vibrations, including the initial condition of the road, its surroundings, could have led to heavy damage to buildings. In other buildings, the damage level was lower, due to different input parameters.

Table 1. Comparison of measured and prescribed limits for building sensitivity to vibrations

	SN	DIN 4150-3	Measured
$v_{a,max}$ (mm/sec) sensitive buildings	1.5-2.5	4	3.429

Table 2. Comparison of measured and prescribed limits for resident sensitivity to vibrations

	DIN 4150-2	mjereno	DIN 4150-2	mjereno
	f kB	max	$v_{a,max}$	max
Stambeno danju	0.4	0.595	0.4	3.429
Stambeno noću	0.2	0.595	0.16	3.429

Table 3. Comparison of measured and prescribed limits for resident sensitivity to working ability

Action description	Frequency range 1 do 10 Hz peak acceleration (mm/sec^2) prescribed vs measured	Frequency range 1 do 10 Hz peak velocity (mm/sec) prescribed vs measured
Barely noticeable	34	0.5
Clearly noticeable	100	1.3
Disrupting	550-434.5	6.8
Unbearable	1800	13.8

CONCLUSIONS

The roads of a small town were used for the crushed stone material transport to the highway construction site from a nearby quarry. The roads were already in poor condition even before the transport started. They were used in a period of three years. During that period, the buildings near the road and their residents experienced significant amount of traffic vibration increase.

Vibrations became constant and long-term annoyance to them. As a consequence, the damage appeared in many of the buildings placed near the road. The damage intensity was dependent upon the building workmanship, age and type. Usually, they were classified as sensitive due to their age and the lack of proper structural integrity. While some of the damage in buildings could be considered insignificant, the other however even lead to collapse of structural elements.

After some period of time, the residents of damaged buildings initiated a lawsuit on road maintenance company. It was needed to prove that the damage in their buildings was caused by traffic-induced vibrations, and not by other causes.

In that purpose the reconstruction of the events was conducted, in which the conditions leading to damage were simulated. This was not possible in total, since the road was meanwhile repaired completely. The road was without irregularities and didn't had such extreme traffic loading. This was overcome by introducing the wooden board to the road over which the heavy truck was passing several times. The weight of the truck and speed were in compliance with the standards for vibrations measurement.

Only on four of eight buildings vibrations were measured.

Based on the measured vibration intensity and by comparing them with by standards allowed values, conducted was assessment of the building condition. The effect of traffic-induced vibrations was higher on older buildings that had less structural stiffening elements and are considered as sensitive buildings.

The measurements confirmed the coincidence of building resonant frequency and dominant excitation frequency which can be served as a proof for the building damage. Additionally, the vibrations had disruptive and unbearable effect on residents.

Non-maintenance of town roads and non-planned usage with significant increase of heavy truck traffic caused the damage to many buildings near the road and annoyance to the residents. One of the most important things in planning a building construction is not to jeopardize the other buildings.

Note:

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