

CETRA²⁰¹⁴

3rd International Conference on Road and Rail Infrastructure
28–30 April 2014, Split, Croatia

Road and Rail Infrastructure III

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INFLUENCE OF TRAM INDUCED VIBRATION ON UNDERGROUND GARAGE STRUCTURE

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Abstract

Light rail traffic presents significant advantages in a heavy populated urban environment in terms of quality of service, volume of passengers, delays etc. Vibrations caused by tramway vehicles passing through highly populated urban areas present a great impact on the quality of life of citizens. Beside the life quality, severe vibrations can also influence structural integrity of surrounding buildings and other infrastructure. In a crowded urban environment, underground structures such as underpasses, garages or water supply and sewage facilities are often located directly under the rail track structures. In such scenarios, special attention has to be pointed to track design in terms of vibration attenuation, as well as underground structure design in respect to additional dynamical loads presented by the overhead rail traffic. The paper presents a case-study of vibration measurement and analysis on an underground garage constructed under a tramway line on Kvaternik square in Zagreb. Rail discontinuities at turnouts and crossings present an impact point between tram vehicles and the track and therefore induce severe vibrations. To analyse tram induced vibrations and its effects on an underground garage structure, measurements on several locations have been conducted, including square surface and underground garage slab structures. Measurements have been conducted immediately after the construction of the garage and tram track on top of it, and repeated after 6 years of exploitation, using same principles and under same traffic load. This way the influence of exploitation wear and aging could be evaluated and analysed. Additionally, vibrations in the working environment of underground garage staff have also been considered. Such practice of periodical vibration measurements serves as an early warning system for any unexpected structural defects and provides a tool for future decision making and maintenance works scheduling.

Keywords: floating slab track, tram, vibrations, underground garage, exploitation

1 Introduction

Rail vehicles operation inevitably induces and emits vibrations to the environment. Main source of vibrations of the railway track structures originates from wheel – rail contact surface. In the urban environment the vibrations are transmitted through the ground to surrounding structures that are often found in close vicinity of railway tracks and as such can have a great influence on people living or working in the close vicinity and on structures themselves. To reduce the emission of railway noise and vibrations, two approaches are commonly used; applying mitigation measures to railway vehicles, or applying them to the railway track structure [1]. Taking railway vehicles into consideration, beside the usual geometry and wheel running surface maintenance, great attention has to be appointed to the vehicle suspension and type of wheels installed. For low speed tram and light rail systems found in urban

environment, the use of two-component wheels with elastic components is considered good practice. If railway track is considered, in addition to regular maintenance of running surface, the use of elastic fastening systems and continuously supported resilient tram tracks is recommended [2]. In order to regulate the level of vibrations people are exposed to in their living and working environment, methods of analysis and evaluation have been developed [3]. In the USA, the vibration exposure is covered by the FTA – Transit noise and vibration impact assessment [4], while in the EU, the directive related to vibrations in the working environment is 2002/44/EC [5].

The research consists of vibration measurements on tramway network of Zagreb Municipality Transit System (ZET). ZET operates around 180 tram vehicles along 116 km of narrow gauge tram track (1000 mm), forming the core of Zagreb public transportation system. Actual location of measurements is on a section of a tram track that passes over an underground garage at Kvaternik Square. The square serves as a turning and routing point for six tram lines, since three tramway routes intersect at the square. The tram track layout at the square includes turnouts and crossings, necessary for vehicle manoeuvring. Rail discontinuities at turnouts and crossings present an impact point between tram vehicles and the track and therefore induce severe vibrations. Goal of the research was to measure and evaluate the type and intensity of vibrations that are transmitted from the tram track to the underground garage underneath it. To analyse tram induced vibrations and its effects on an underground garage structure, measurements on several locations have been conducted, including square surface, underground garage slabs.

First vibration measurement and analysis has been carried out in 2008, immediately after the square reconstruction which included construction of the underground garage as well as the tram track on top of it, Fig. 1. The measurements have been repeated in the same way, 6 years into exploitation, in 2014 in order to record and analyse the difference of vibration propagation and intensity.

2 Description of test location

Kvaternik square has been reconstructed in 2006-2008. The project included construction of an underground 3 story garage underneath the surface of the square. Underground garage is a reinforced concrete structure resting on piled foundations. The project also included reconstruction of tram tracks on the entire square. Most of the tram tracks had to be completely rebuilt on top of the newly erected underground garage, Fig. 1. During the construction phase, the tram lines had to be diverted to different routes in order to clear the traffic of the construction site.

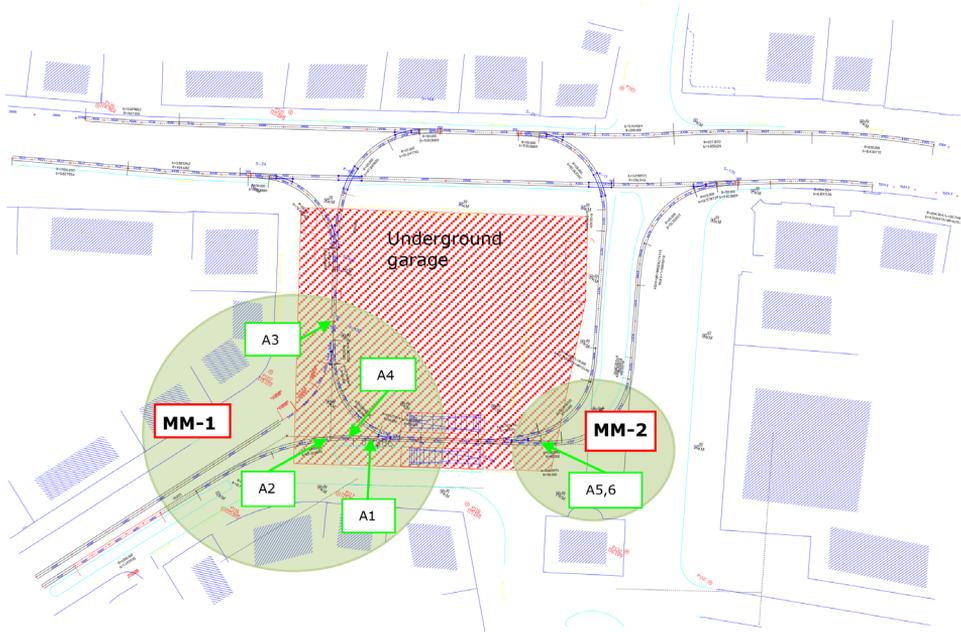


Figure 1 Kvaternik square layout with measuring locations

Since the new tram track rested directly on top of the garage upper concrete deck (at a ground level), measures for vibration attenuation had to be considered. For this purpose, the standard system of tram track in Zagreb (concrete slab, discrete rail supports and double elastic fastening system – DEPP) has been additionally fitted with continuous elastic supports underneath the rail and an asphalt layer beneath the concrete slab, Fig. 2.

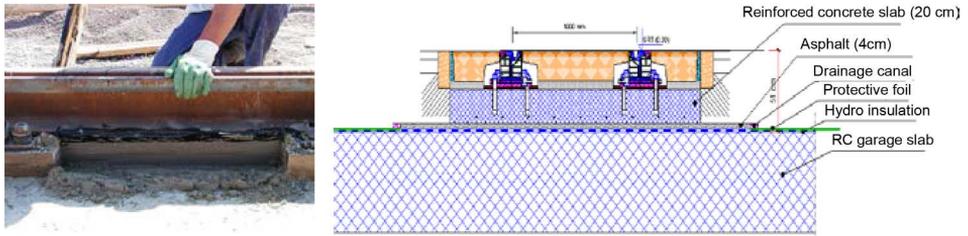


Figure 2 Cross section of floating tram track structure on top the garage slab of Kvaternik square with continuous under rail support (left) and asphalt levelling layer (right)

Continuous under rail support has been proven to reduce vibrations and noise in similar conditions [6]. The entire slab track structure rested on the poured asphalt layer, making it a floating slab track. Expected vibration attenuation of such track structures is between 10 – 25 dB, in 16 – 250 Hz frequency range [3]. Other characteristics of the system are the Ri60 grooved rails and paving of the track with reinforced concrete blocks.

3 Measurement and analysis procedure

Measuring points layout has been noted in Fig. 2. Two Measuring zones have been established – MM1 and MM2. Both zones are in close vicinity of the turnouts. Measurements have been carried out using 6 accelerometers (A1 – A6) fitted to the ground level (near the railway track), to the ceiling of the -1 garage level (surface RC slab) and on the floor of -1 garage level (-1 floor RC slab), visible on the garage cross section in Fig. 3.



Figure 3 Kvaternik square garage cross-section with measuring locations

All the vibrations have been measured in the vertical axis, perpendicular to the square plain. Since the location has quite heavy tram traffic, all of tram types running at ZET network have been recorded (T4, KT4, GT6, TMK2100, TMK2200, TMK2300). In the following analysis the focus is on two most frequent tram types recorded in 2008 and 2014, T4 and TMK2100 in order to make valuable comparison.

3.1 Data collection and presentation

Measurements have been carried out using Brüel & Kjær multichannel PULSE analyser. Vibrations of accelerometers A1 – A4 at MM1, as well as A5 – A6 at MM2 have been recorded simultaneously in order to evaluate the difference between surface vibrations at the source with the vibrations at different points in the garage structure. In 2008 a total of 32 tram passes have been recorded at MM1 and 18 at MM2. In 2014, 15 tram passes have been recorded at MM1 and 9 at MM2.

3.2 Data analysis

Time related accelerations have been recorded and connected to the passing vehicle. Each record has then been integrated in order to get speed of vibrations [mm/s] and spectral analysis has been performed in third octave bands in the range of 0 – 100 Hz.

3.2.1 Vibration propagation through the structure

MM1 zone has been established in order to record the influence of vibrations on different parts of the underground garage structure (see Fig. 1 and Fig. 3). It has been noted that the vibrations of the -1 floor (A2) have the higher value of measured vibrations that the upper slab

(A3, A4) of the garage. This was in conflict with the presumption that the vibrations would decrease the further we go from the source. However, due to the smaller construction height of the -1 slab, the vibrations have a greater influence on it than on the surface slab (Fig. 4).

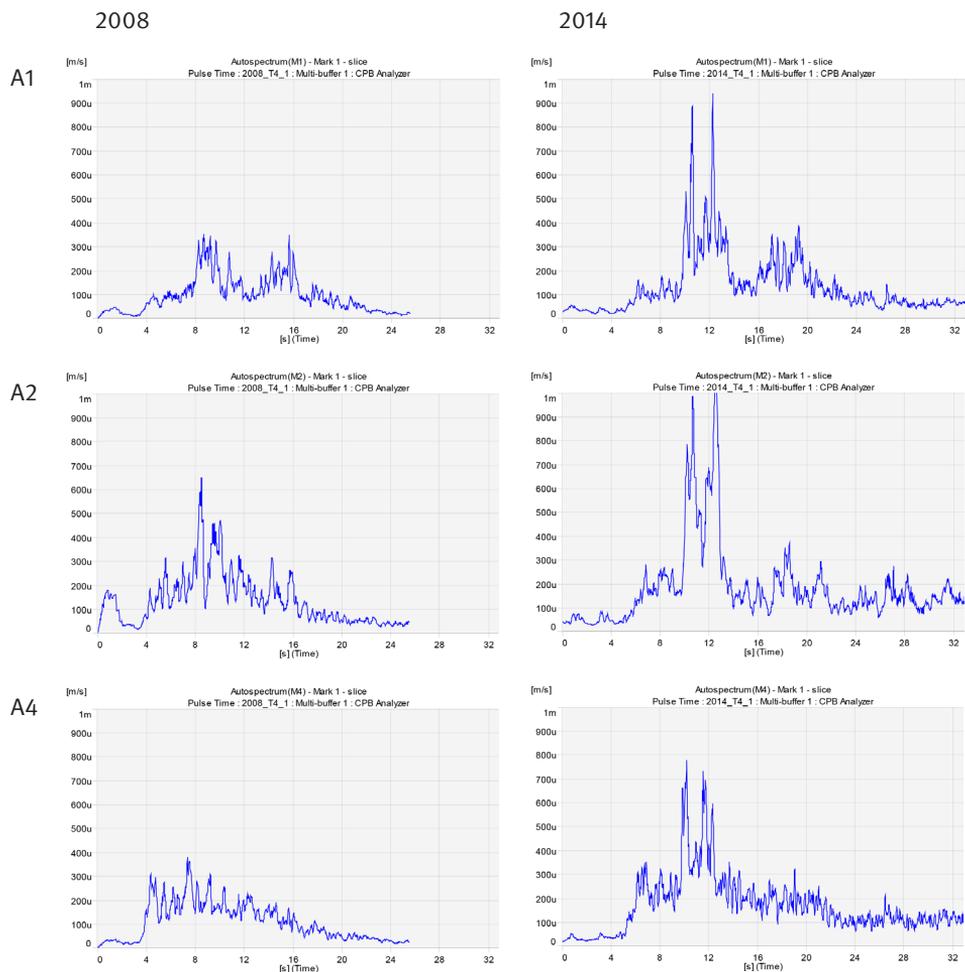


Figure 4 Speed of vibrations at MM1 (A1, A2, A4) for tram T4 in ‘08 and ‘14

It can be seen that the vibrations have increased in intensity over the 6 years of exploitation. As presented in one of representative measurements (pass by of T4 tram at MM1 (direction 1), increase in vibration speed can be observed (Fig. 4).

Increase in vibration intensity can be explained by the rail and turnout wear through exploitation, which results in surface irregularities and larger rail discontinuities at turnouts and crossings. This has been confirmed by a visual inspection and measurement of rail cross section. The intensity of vibrations has not increased to the point that it would cause any damage on the structure itself, but it could have an impact on the working environment of garage staff.

3.2.2 Vibrations in the working environment

Measurement zone MM2 has been positioned in the zone of a turnout that sits on top of a control room of underground garage staff. Accelerometers A5 and A6 have been fitted inside one

of the control rooms in order to measure vibrations in working environment. Vibration recording of a TMK 2100 passing by MM2 (A5) has been presented in Fig. 5 for both 2008 and 2014.

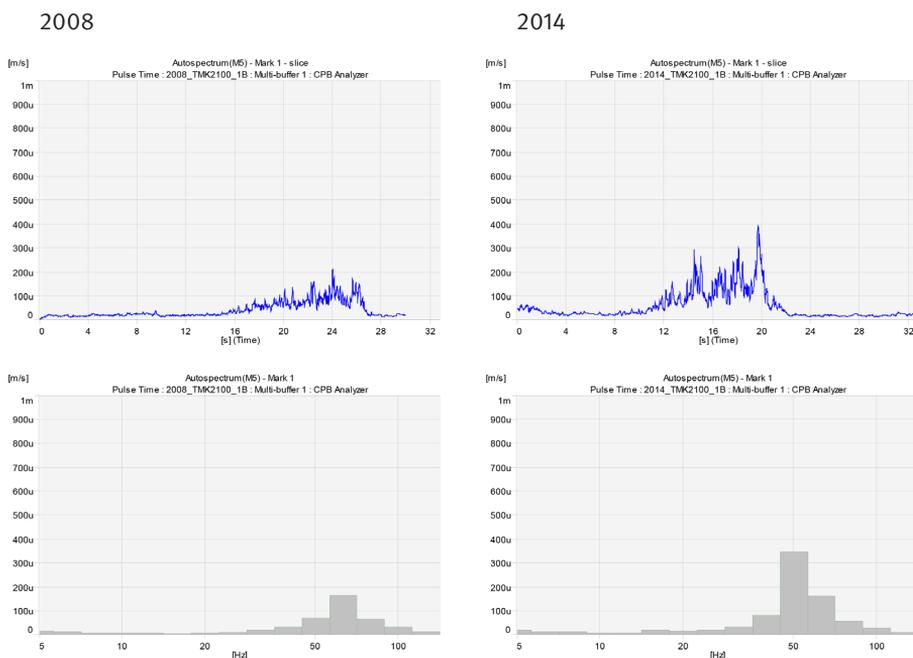


Figure 5 Measurements at MM2 (A5)

According to ISO 2631-2:1985, the measured value of vibrations in 2014 of 0.35 mm/s at 50Hz has passed the limit of 0.2 mm/s set by the standard. This is however just an indication, because 8h long measurements should be carried out and calculated as the highest (rms) value, or the highest vibration dose value (VDV) of the frequency-weighted accelerations, determined on three orthogonal axes, according to Directive 2002/44/EC.

4 Conclusion

Vibrations caused by railway vehicles are often a problem in an urban environment. At smaller frequencies they can produce squealing noise, and at larger frequencies, vibrations can disturb and harm humans in their living and working environment. Moreover, severe vibrations can threaten the structural integrity of the objects surrounding the railway line.

In Zagreb, ZET Municipality transit system is maintaining 116 km of tram track, mostly through highly populated urban area. An important design and maintenance task is to provide effective solutions for the tram track and tram vehicles in order to keep the low level of vibrations. In certain specific cases, like the one described in the paper, the tram track is located directly on top of the underground garage top slab. In order to achieve vibration attenuation properties of the track, a floating slab track has been designed and constructed under the supervision of the University of Zagreb Faculty of Civil Engineering. Such a demanding structure had yet to be evaluated in terms of vibration attenuation. Measurements have been conducted at the beginning of exploitation period in 2008 and in 2014, 6 years into exploitation.

Measurements and data analysis have indicated the vibrations have slightly increased over the exploitation period. The more distinguished peak values, and visual inspection of rail, turnout and crossing wear, indicate that the increase in vibrations is due to irregularities

and discontinuities of the rail running surface, especially on the tracks under heavier usage. Therefore, great attention should be appointed to the maintenance of running surface as well as turnout and crossing geometry. The overall vibration level has still remained relatively low and is not causing any structural damage.

Analysis of vibrations at MM2, in the working area of underground garage staff, an increase in vibrations intensity has also been noticed. To fully evaluate the level of vibration that workers are exposed to, extensive measurement and analysis should be conducted according to 2002/44/EC.

The goal of achieving greater attenuation of vibrations than on a standard tram track system installed in Zagreb has been reached by constructing a floating slab track with continuously supported rail and the asphalt pad between the track slab and underground garage slab. The practice of periodical vibration measurements serves as an early warning system for any unexpected structural defects and provides a tool for future decision making and maintenance works scheduling.

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