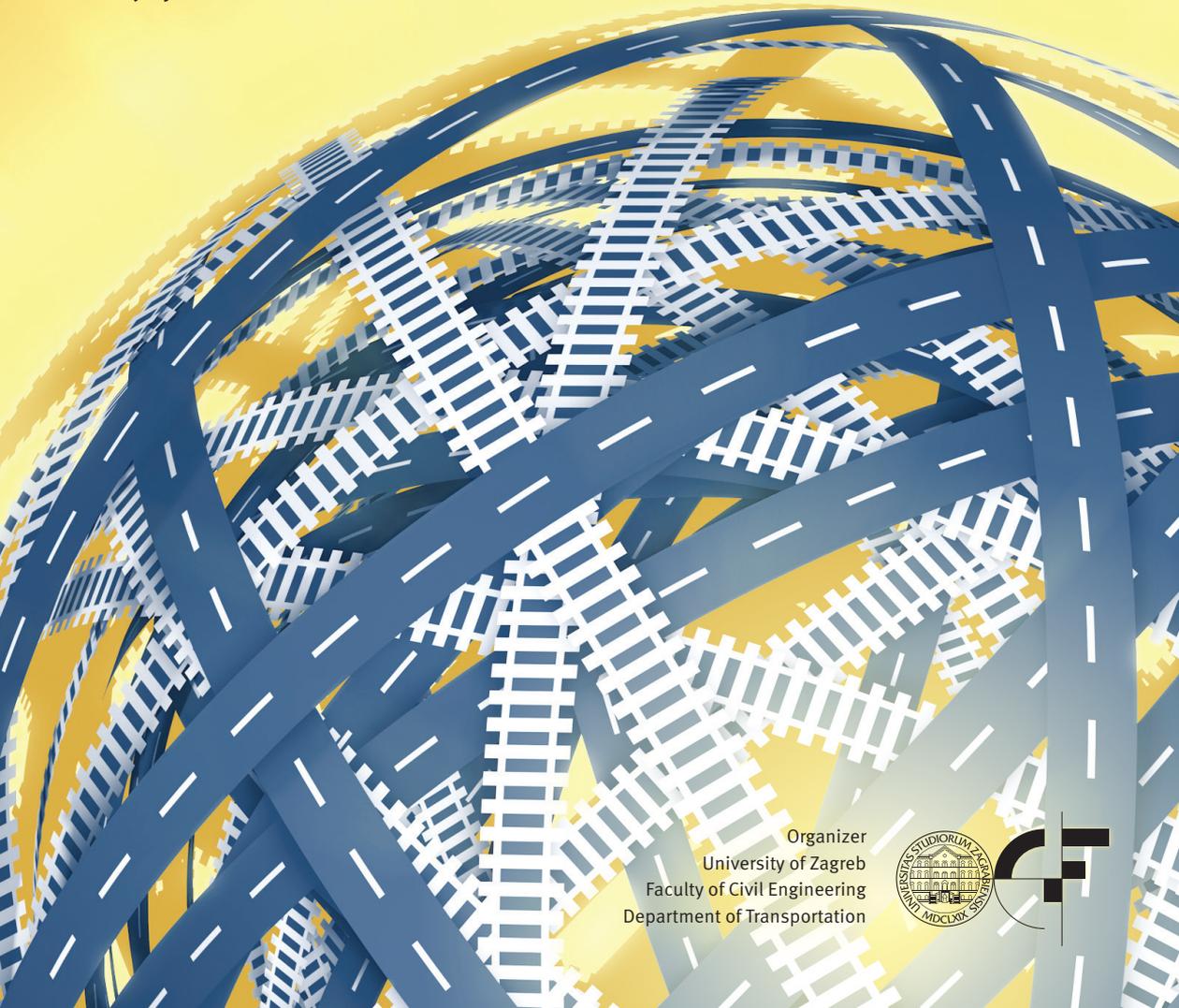


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4<sup>th</sup> International Conference on Road and Rail Infrastructure  
23-25 May 2016, Šibenik, Croatia

## Road and Rail Infrastructure IV

Stjepan Lakušić – EDITOR



Organizer  
University of Zagreb  
Faculty of Civil Engineering  
Department of Transportation



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# Road and Rail Infrastructure IV

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## MONITORING OF DYNAMIC PROPERTIES OF NEW TYPE OF TRAM TRACK FASTENING SYSTEMS UNDER TRAFFIC LOAD

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### Abstract

Light rail and tram traffic present significant advantages in a heavy populated urban environment in terms of quality of service, volume of passengers, delays etc. Rail vehicles in interaction with a railway structure, however, can induce vibrations that are propagating to surrounding structures and cause noise disturbance in the surrounding areas. Since tram tracks often share the running surface with road vehicles it is also of most importance to construct long lasting and low maintenance structures in short traffic closure periods foreseen for these activities.

Tram system forms a backbone of public transport in the City of Zagreb. In the last decade, its fleet has been renewed by 142 new low-floor trams. Shortly after their introduction, it was observed that they have a negative impact on the exploitation behaviour of tram infrastructure, primarily on the durability of rail fastening systems. To tackle this challenge, improvements to the standard fastening systems on Zagreb tram network have been proposed. New fastening systems 21-CTT and 2 21-STT have been installed for testing purpose in Savska street in Zagreb on a 150 m long test section, along with the referent test section of standard ZET fastening system PPE (fastening system with enhanced resilience).

Paper presents an overview of the newly implemented fastening systems, their implementation on a test section in Savska street, as well as measurements and analysis of strain in RC slab and rail vibrations driven by tram pass-by.

*Keywords: tram track, 21-STT, 21-CTT, vibrations, strain*

### 1 Introduction

In the last decade, systems manager Zagreb Electric Tram Ltd (ZET) has renewed its fleet by purchasing 142 new low-floor trams TMK 2200, changing the conditions on the tram network in terms of power demand, loads transferred to the track, wheel-rail interaction mechanism etc.. Shortly after the introduction of new low-floor trams, it was observed that this fleet modernization has increased exploitation demands on other components of tram infrastructure [1]. i.e. the power supply system and track superstructure. These changes in tram track exploitation parameters have caused more frequent rail fastening system failures, which reflected in the increased rail wear and accelerated track geometry degradation. In event of such mayor rolling stock renewal, track structure parameters have to be evaluated [2], [3] and modified. Because of that, ZET Ltd has decided to adjust existing rail fastening systems to the new track exploitation conditions. This was done through technical collaboration with the University of Zagreb Faculty of Civil Engineering, considering the vast experience and expertise in design and supervision of railway and tram track structures.

When developing any new rail track system, after careful design reviews, component testing etc. it was decided to conduct monitoring of new fastening systems exploitation behaviour. This was done by construction of the test track section with built-in new fastening systems [4]. On it, the following continuous and periodic measurements were made:

- visual inspections of track superstructure,
- measurements of track and weld geometry,
- measurements of stresses and strains of tracks reinforced concrete foundation slab, and
- measurements of the tracks dynamic properties (i.e. vibration damping).

## 2 Characteristics of new fastening systems

The primary role of the rail fastening system is positioning and fixing of the rails and transferring the vehicle load from the rails to the track substructure. Generally, the type and characteristics of fastening system is chosen depending on the required elasticity of the track, planned load and type of rail. On major part of Zagreb tram tracks, grooved rails are discreetly laid on the levelling layer, made out of micro synthetic concrete, built on reinforced concrete slab. Standard fastening system used on a large part of ZET tram network is indirect elastic fastening system with decreased stiffness PPE (Figure 1.b) with 50 MN/m stiffness, developed during the 1990s in order to increase tram track life span, and used on about 15% of network. This and other commonly used track fastening systems (ZG 3/2 and DEPP) reflect state of the art and demands for exploitation from the beginning of 1990s which do not meet today's highly complex exploitation requirements on Zagreb's tram tracks:

- large tram traffic volume (individual sections of Zagreb's tram tracks have a traffic volume of up to 15 million gross tons per year),
- high vehicle passing frequency (vehicle frequency is less than 90 s on individual sections),
- high wheel loads on low-floor trams (more than 3.5 tons per wheel),
- strict tolerances regarding the narrow, 1000 mm gauge, track geometry.

Based on the above requirements, during the last few years the Faculty has developed five different concepts for new fastening systems. Two of them, with working titles 21 CTT (Classic Tram Track – the name was chosen because the structure of the system is an upgrade of the existing indirect elastic systems) and 21 STT (Slab Tram Track), were chosen for further development. Their characteristics, production requirements and installation methods best match previous experiences in the construction and maintenance of tram tracks in Zagreb.

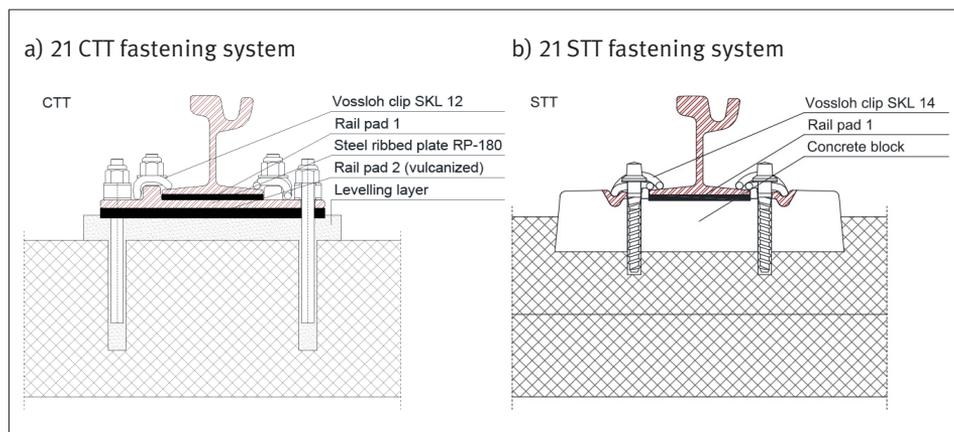
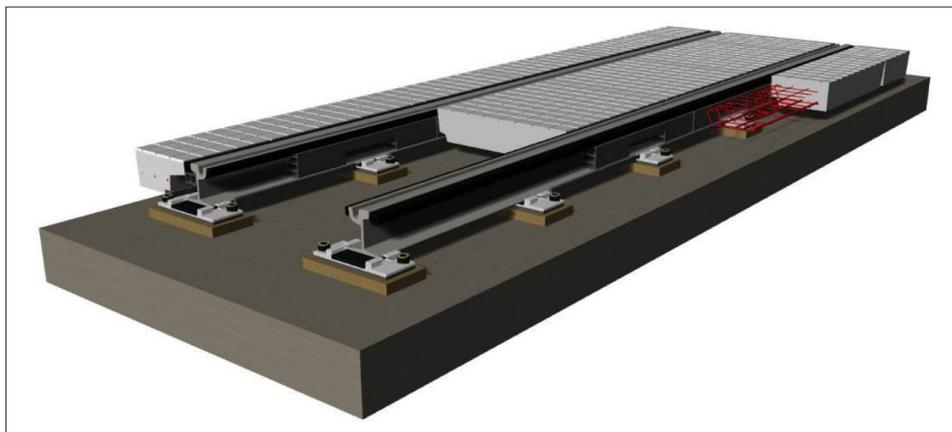


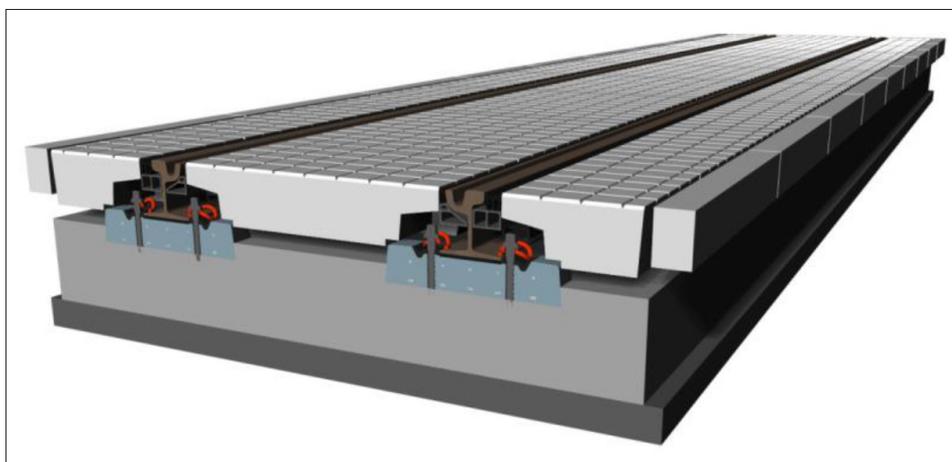
Figure 1 Schematic cross sections of rail discrete bearings with 21 CTT and 21 STT fastening systems

21 CTT system (Figure 1.a) places the rails discreetly on the levelling layer, made out of micro synthetic concrete, built on reinforced concrete slab (Figure 2.). The distance between supports is one meter in the tram rolling direction. The rail foot is supported by neoprene pads placed on ribbed steel plate, laid on the levelling layer. To ensure the durability of individual components and ease the installation during construction and dismantling during the track reconstruction, the underside of the ribbed steel plate is fitted, by vulcanization process, with elastic pad. Vulcanization process enabled production of a compact element electrically isolated from other components (anchors), but also provided for additional elasticity of the whole fastening system.



**Figure 2** Design model of tram track structure with 21 CTT fastening system

21-STT system (Figure 1.b) represents a completely new solution for tram tracks superstructure construction in Croatia. Its main advantage over the previous systems is that the levelling layer (which is quite difficult to construct) are replaced by two block precast concrete sleepers laid on reinforced concrete base slab, one meter apart (Figure 3.). Upper reinforced concrete slab is constructed after track horizontal and vertical alignment adjustment. This is a direct elastic fastening system, with one elastic pad between the rail foot and block sleeper.



**Figure 3** Design model of tram track structure with 21 STT fastening system

### 3 Construction of test section and

In order to determine exploitation characteristics of newly developed tram track fastening systems and get detailed insight into the behaviour of its elements and the track structure as a whole, in the spring of 2014 a plan and program of test track section construction and monitoring in Savska Street was adopted. The said track section was, according to track maintenance program, planned for reconstruction due to its deterioration. For the purpose of the research, the section was divided into three sub-sections. The first sub-section is designed as a reference and reconstructed using the standard PPE fastening system. The second reconstructed sub-section is fitted with a 21 CTT fastening system, and the third is reconstructed as 21 STT system (Figure 4).

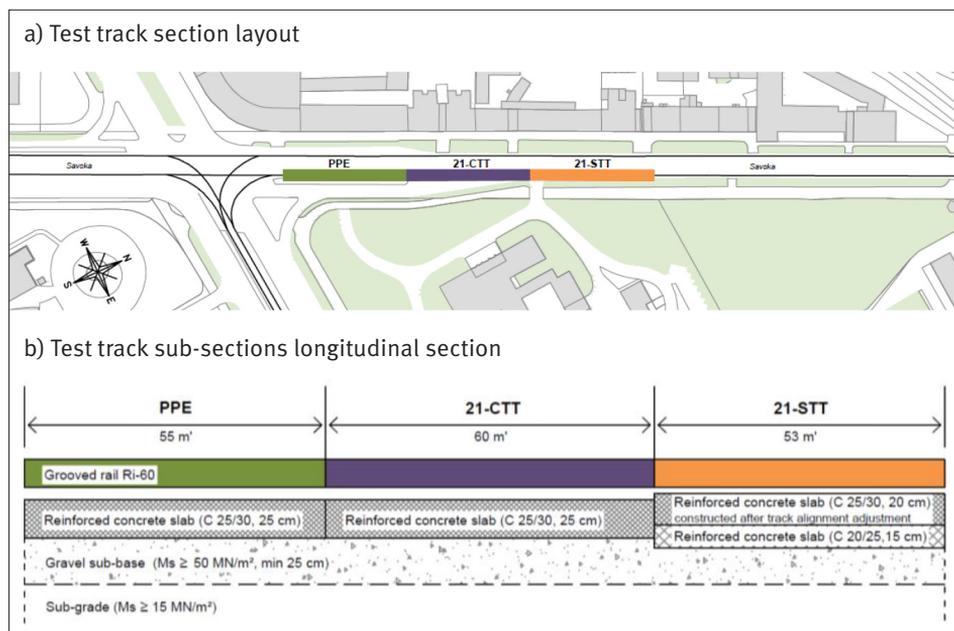


Figure 4 Test track section in Savska Street

A brief overview of construction work on subsections can be observed in Figure 5. Demolition of old track (a), construction of the new mechanically compacted base layer (b), construction of new reinforced concrete slab and fitting of strain gauges (c), construction of the bearings with fastenings and rail mounting (d, e), casting the top concrete slab to cover block sleepers of 21-STT (f).

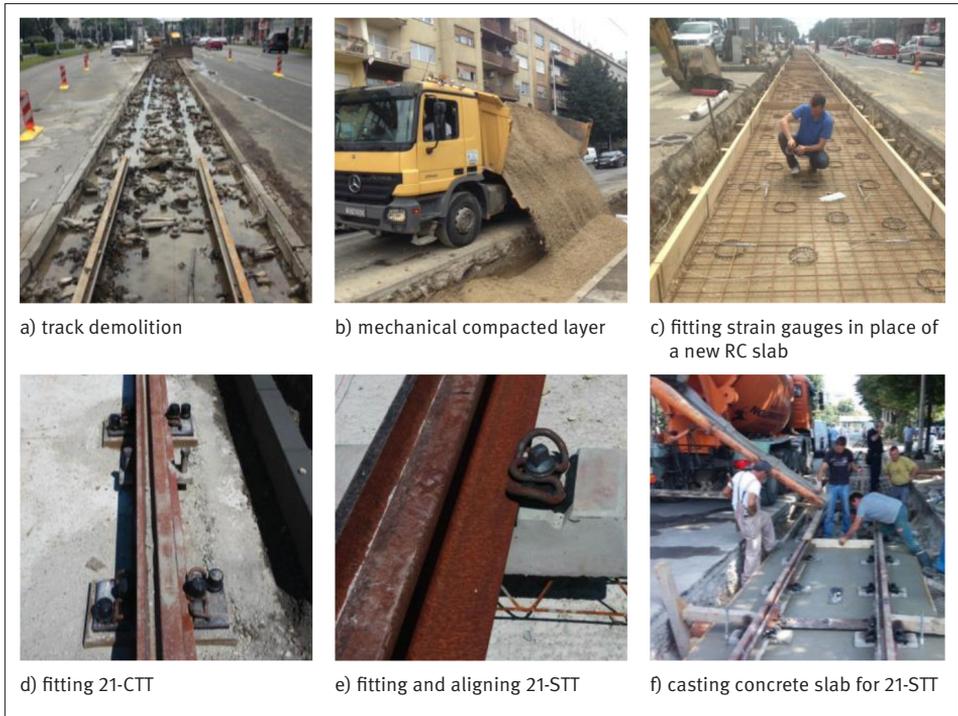


Figure 5 Construction steps at test section in Savska street

#### 4 Tram track strain and deformation monitoring

During the construction process of test section, strain gauges have been fitted inside the bearing reinforced concrete slab. Total of 12 sensors have been fitted, 4 at each subsection (PPE, 21-CTT, 21-STT), of which two in longitudinal and two in lateral direction. Sensors have been fitted to the tensile zone of the slab, attached to reinforcement and afterwards covered in concrete. Sensors cabling has been installed up to a revision shaft on the side of the track, where the data collection system MGC+ could be connected at any time without interrupting traffic. By detecting change in voltage, sensors read the relative deformation of reinforcement. With presumption that the reinforcement is properly anchored in concrete slab, and with known modulus of elasticity of concrete, strain can be expressed in the bottom zone of RC slab.



Figure 6 Position of strain gauges on reinforcement rod – 21-STT

Strain reading on the bottom of concrete slab is a good indicator of load distribution through the track structure, influence of dynamic load on the lifespan of structure and possible cracks in the track structure. Strain measurements have been conducted under dynamic load of empty vehicle TMK 2266 pass by at the speed of 15 km/h and 30 km/h which are to be expected at this section. Data has been collected with sampling frequency of 50 Hz, giving a strain reading every 0.02 sec. Measurement results are shown in Table 1, where the overview of maximum strain readings of track structures is presented (for PPE, 21-CTT and 21-STT) for tram speed of 30 km/h.

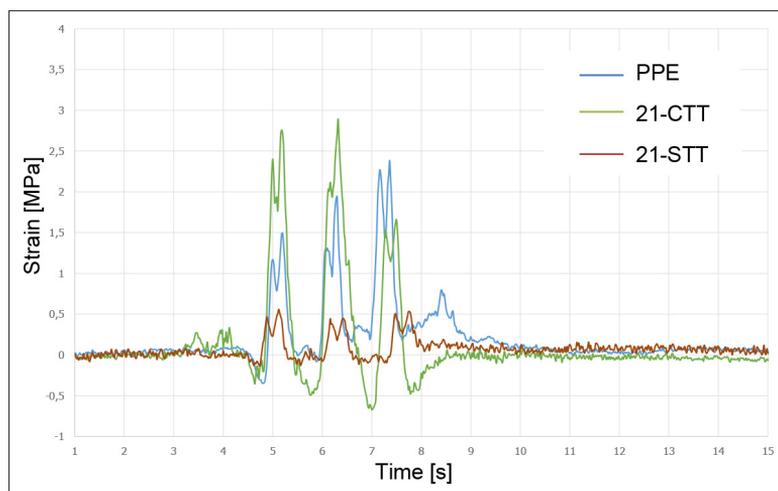


**Figure 7** Conducting strain measurements section 21- STT (left) and vibration measurements at section 21-CTT (right) under vehicle pass by

**Table 1** Values of strain readings in bottom zone of RC slab

Maximum strain reading [MPa]						
Section	PPE		21-CTT		21-STT	
Direction	LONG	LAT	LONG	LAT	LONG	LAT
24.11.2014.	2,38	1,87	2,89	3,33*	0,56	0,73
04.03.2015.	3,33	2,25	2,26	1,14	0,86	1,01

*\*sensor is located near a rail weld of poor geometry so additional strain is to be expected*



**Figure 8** Time record of strain under vehicle pass by at PPE, 21-CTT and 21 STT, longitudinal direction

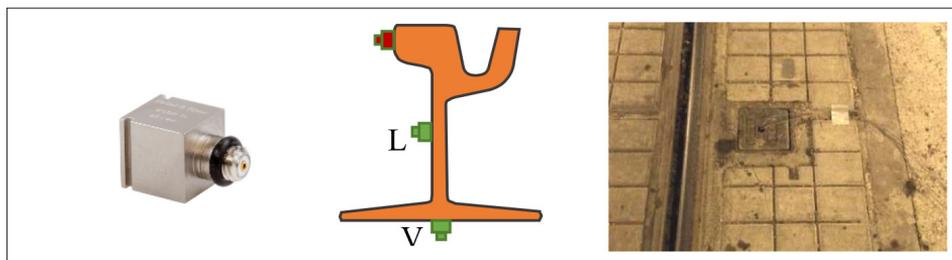
By comparing the continuous time record of strain at all subsections (Figures 8 and 9) it is evident that 21-STT structure has very good load distribution to lower structure layers. Strain in this structure is around 3 times smaller than the other two observed subsections. It is also visible that structures 21-CTT and PPE have similar strain measurements, as it was to be expected since similar fastening elements have been used.

## 5 Vibrations measurements

The main sources of noise and vibrations on rail tracks are the propulsion noise of locomotives and power cars coming from the engines, aerodynamic noise that occurs at very high train speeds, and wheel/rail interaction. The latter is the main noise and vibrations source in urban rail traffic, where the vehicle speed is not high enough to take into account aerodynamic noise [5]. When vehicles run on the tracks, their weight coupled with the dynamic forces resulting from running surface irregularities causes oscillations i.e. vibrations of rail vehicles and whole track construction. At high frequencies (100-5000 Hz), the energy of these vibrations is propagated through the air in the form of sound waves (noise). Lower frequency vibrations (0-100 Hz) are transmitted from rails to the lower parts of track structure and surrounding soil [6]. On test track in Savska Street, vibrations have been measured under tram traffic load in order to establish attenuation property of the subsections. Pass-by vibration measurements have been conducted under constant speed of 30km/h of an empty tram, garage number TMK2266. This measurement setup has been used in order to establish unified excitation of vibrations during the experiments.

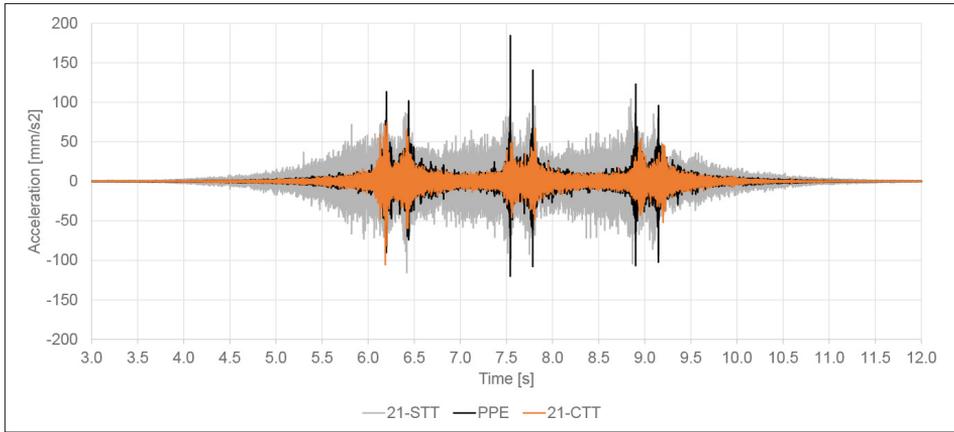
### 5.1 Measurement procedure

To determine dynamic properties of a railway track, vertical and lateral vibrations have been measured under vehicle pass-by. Accelerometers for vibration measurements have been fixed to the rail by means of magnet, and the access to the rail has been ensured by installing revision shafts near the rail while constructing the test section, Figure 9.



**Figure 9** Acceleration sensor fixed to rail foot and rail web, inside a revision shaft

Measured vibration signal is recorded in time domain and can be observed simultaneously for different test sections, Figure 10. Peaks in the diagram correspond to wheel pass by over the microphone.



**Figure 10** Time signal of recorded rail vibrations in vertical direction on all three subsections

### 5.2 Data analysis

To quantify the level of vibrations, the expression of equivalent vibration level,  $L_{Veq}$ , has been calculated according to:

$$L_{Veq} = 10 \log_{10} \left[ \frac{\frac{1}{T} \int_{t_1}^{t_2} V^2(t) dt}{V_0^2} \right] \text{ dB} \quad (1)$$

Where:

- $V^2$  – level of vibrations,
- $V_0^2$  – referent vibration level of  $1 \mu\text{m}$ ,
- $T$  – time interval [7].

Using formula (1), equivalent levels of vibrations have been expressed for each subsection, Table 2

**Table 2** Equivalent level of vibrations during a tram TMK 2266 pass by at 30 km/h

	PPE	21-CTT	21-STT
$L_{Veq}$ (dB)	117.0	114.5	122.6

From calculated equivalent vibration levels of a tram pass-by (interval of 9 sec) it can be concluded that in respect to referent subsection PPE, section 21 CTT has achieved reduction of vibrations by 2.5 dB, while subsection 21 STT measures increase in vibrations of 4.6dB. This increased vibration level can be prescribed to stiffness of the whole track structure on 21-STT section which could be reduced by adding different under rail pads.

## 6 Conclusion

Due to high traffic loads, tram tracks in the City of Zagreb are exposed to high stresses, they rapidly degrade and deteriorate. To answer the harsh tram traffic operation conditions, and to optimize maintenance procedures, two new solutions for rail fastening systems were developed, named 21-CTT and 21 STT systems. The main objective in developing the new systems

was to develop a tram track structure which would be quick and simple to construct, have longer exploitation life, be easy to maintain, and have good exploitation characteristics. By measuring and analysing dynamic properties under vehicle pass by-at constant speed, it can be concluded that 21-STT shows significant reduction of strain measured in bottom layer of concrete slab, because of better load distribution through the structure. Vibration attenuation, measured by determining rail vibrations, under tram pass-by at constant speed shows reduced level of vibration on 21-CTT section in respect to referent section PPE, as a result of carefully selected vulcanized elastic elements of rail fastenings. 21-STT however shows a higher level of vibrations due to a much stiffer under rail pad and overall track stiffness, which can be reduced by introducing different elastic fastening elements.

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