Noise and vibrations at tram track intersection

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In urban areas noise and vibration due to public traffic diminish the quality of life. In Zagreb, tram traffic is the most important form of public transport. Tram network has 120 km of the tracks and 190 trams are used for passengers transport every day. In the movement of the vehicle over track, the interaction between the wheel and track plays the most important role in the field of noise and vibrations. The increasing of noise and vibrations are particularly emphasized at track intersection where a given number of track switches and crossings are installed. This paper presents an experimental study of noise and ground vibrations through the passage of three types of tram vehicles. The measurements were done on the tram intersection with the highest traffic volume in Zagreb's tram network. Two types of track construction were analyzed, discrete and continuous rail fastening system. During the track reconstruction at this intersection, the existing discrete rail fastening system was replaced with a continuous. Because of that, the measurements were carried before and after reconstruction at the same test points. Test results have showed significant reductions of noise and vibrations at track intersection in the case of continuous rail installation.

1 Introduction

In urban communities, traffic on rails has great advantages in relation to the road traffic, especially if separate corridors are ensured, whereby traffic on rails is separated from the road traffic. Without regard whether the rails are executed in the same level or on an object or in tunnels, special attention must be paid to vibrations, which occur because of vehicle movement on the rails. An increased level of noise and an increased intensity of vibrations are especially expressed on those parts of the rail network, where tracks are situated immediately near the buildings [1]. Additional increased noise and vibrations are especially expressed on places of tram crossings, where a certain number of switches and crossings are built in. In Figure 1, a regular tram crossing is shown, paved by concrete slabs, which is the usual manner of pavement in the city of Zagreb.

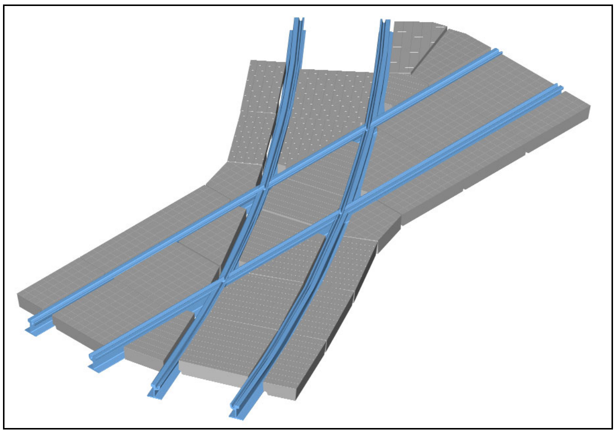


Fig.1 Survey of crossing paved by concrete plates.

Especially, 4 to 5 years after building in of crossings and switches, it usually comes to a significant increase of noise and vibrations. The reason for that is the fact it then comes to the wearing out or the so called "shallow groove". The existence of a shallow groove in tracks executed with grooved rails is the usual manner to ensure the passing of vehicle wheels over assemblies without impact. Namely, on a part of the traffic lane crossings, vehicle wheels are driving over wheel flange outlets (Fig. 2a). After wearing out of the shallow groove, traffic lane interruptions appear, causing impacts because of passing of vehicle wheels, because the wheels are no longer driving on the wheel flange outlet but on the wheel tread, Figure 2b.

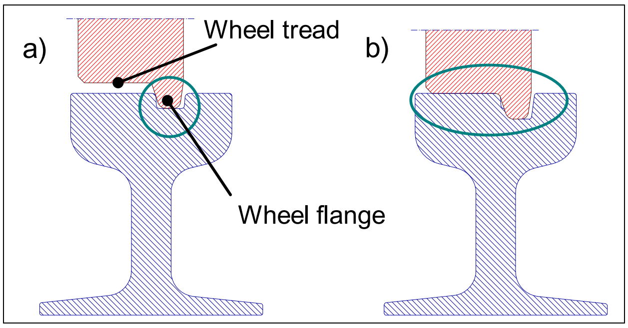


Fig.2 Wheel movement over crossings: a) new crossing; b) worn crossing

Because of a large number of complaints by citizens regarding noise and vibrations appearing because of tram traffic on Jurisiceva-Draskoviceva intersection, the company of Zagreb Municipal Transit System (ZET) contracted the Faculty of Civil Engineering at the beginning of 2006 for the provision of a technical solution aimed at the reduction of adverse impacts on humans and on the surrounding buildings. The tram track structure at the crossing was performed by way of a discrete system of track leaning on the base (distance of fastening 1 m), while the track pavement was performed by AB plates. By the Terms of Reference it was asked for a decrease of noise and vibrations, provided that the existing bearing places are kept, as well as the existing manner of track closing. For the purpose of vibration reduction, continued track leaning, by way of the use of the material Icosit KC 330U, a system that was previously completely tested on the testing range [2] was proposed. A continuously leaning track ensures a better transmission of forces to the base, and diminished spreading of noise and vibrations caused by trams moving [3].

Based on the results of the conducted preliminary research and because of the fact that it is necessary to intervene within the track structure, but keeping thereby the existing track fastenings, and the existing system of track closing (by AB mounting/dismounting plates), the proposed solution for noise and vibration decrease was based on the idea that, in the part between the existing bearing places, the rail foot should be coated by an elastic material, however up to a height, which would not interfere with the building in of inserts along the rail collar and the building in of AB plates. A survey of the existing and the proposed track structure is shown in Figure 3 (Fig. 3a – Standard tram structure, TYPE A; Fig. 3b – Modified tram structure, TYPE B).

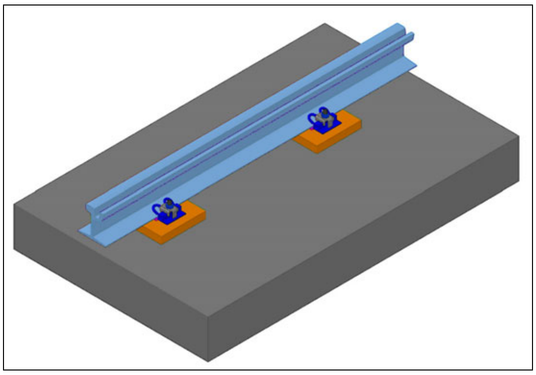


Fig.3a Track structure "TYPE A"

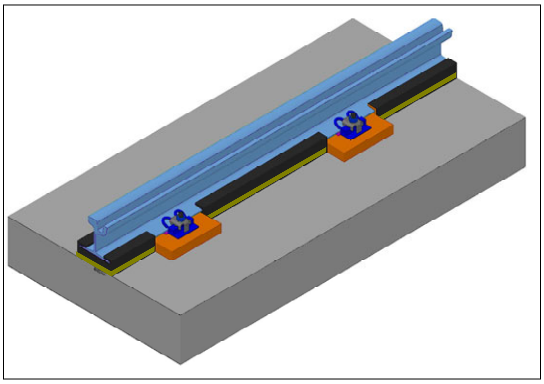


Fig.3b Track structure "TYPE B"

The results presented in this paper have been obtained within the framework of the Scientific Project "Noise and Vibrations on Tram and Railway Tracks", financed by the Ministry of Science, Education and Sports of the Republic of Croatia.

2 Measuring of noise and vibrations

In order to establish the actual effect of the applied technical solution, noise and vibration measurements were conducted, before and after the work on track reconstruction, and that on the same measurement spots. The measurements of noise and vibrations in the field were compared with the results obtained on the testing range [2].

2.1 Description of measuring location

Jurisiceva-Draskoviceva intersection is placed in the very centre of Zagreb and it is very important for the functioning of the tram transport, Figure 4. The intersection ensures the connection of the western and the eastern, as well as the northern and the southern parts of the city. Seven tram lines are frequenting the crossing, Figure 1. Daily, 1004 trams pass the crossing in one direction, and tram tracks are only 5 to 8 m away from business and residential buildings. The ground plan of Jurisiceva-Draskoviceva crossing and the position of the measurement points, on which the measurements were conducted, is visible in Figure 5. Vibration measurements of the base were conducted on measurement points MP-1 (directions: North-South and West-East) and MP-2 (directions: West-East and South-North). The survey of noise and vibration measurement is shown in Fig. 6 and Fig. 7. Since by the "Regulations on Maintenance of Railway Lines and Railway Facilities" a maximum speed of circulation over crossings and switches of 10 km/h is proscribed, the velocities of the vehicles during the measurement were ranging from 7 to 10 km/h. After vibration measurement before reconstruction, works on exchange of tracks, crossings and switches began. When reconstruction works were finished, vibration measurement on the same measurement points, as before the reconstruction, had started.

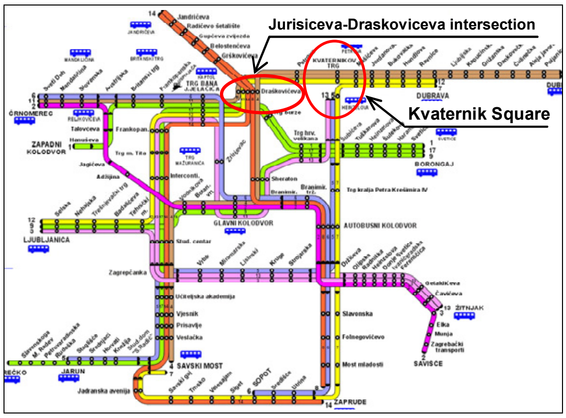


Fig.4 Zagreb tram network plan (120 km of tracks).

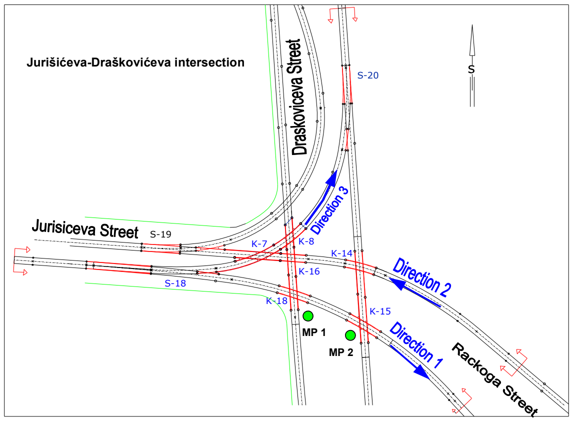


Fig.5 Scheme of Jurisiceva-Draskoviceva intersection.

Fig.6 Measuring of noise and vibrations.

Fig.7 Sound level meter and accelerometers (MP-2).

2.2 Measurement of vibration

During the measurement before reconstruction, noise and vibrations of the base caused by 48 trams passing were recorded, while during the measurement after reconstruction, noise and vibrations caused by 43 trams passing in a similar time period, 60 minutes, were recorded. Since it is impossible to show in this paper all the recorded data, vibration measurement results obtained by the passing of identical tram types at the same driving speed, are presented. Two types of trams were selected, passing over the crossing most frequently, tram TMK 2200 (manufacturer KONCAR – Croatia) and tram T4 (manufacturer CKD Tatra – Czech Republic). In order to be able to compare the measurement results before and after reconstruction, all measurements were conducted by means of the same measurement equipment, and data processing was conducted in the same way.

For the measuring on the tracks, six accelerometers were used, which were placed on 2 steel devices, weight 180 N, which were placed on asphalt base near the tram track, at a distance of 2.0 m from the tracks, Figures 6 and 7. Vibrations were measured at the moments of tram passing over the period of 20 seconds in three perpendicular directions: vertical direction (axis z) and two horizontal directions (axis x and y). Axis x was in the direction of vehicle movement, while axis y was perpendicular to the track axis, but in the level of the upper edge of the tracks. The temporal recording of the vibrations for all three axes at the same amplitude scale of ± 2 m/s^2 in the time period of 20 s, measured at the measurement point MP-1 during tram TMK 2200 passing at a speed of 10 km/h, is shown in Figure 8. Dominant vibrations are in the direction of axis z, as it is visible in Figure 9, so the frequency analysis was made only for the vibrations in the direction of axis z, [6].

Vibrations were recorded in their original form by means of a multi-channel analyzer Brüel & Kjær PULSE and the "Time Data Recorder" program, and the analysis of the results was made later on in the lab. Vibration accelerations were recorded (m/s^2), and after the integration of the recorded signals, effective values of vibration speeds (mm/s) within the frequency range up to 1 kHz were analysed. The relevant third-octave spectra with linear amplitude scales (mm/s$_{RMS}$) at the moments of maximum vibrations are shown in Figure 10 (passing of TMK 2200 tram) and Figure 11 (passing of T4 tram).

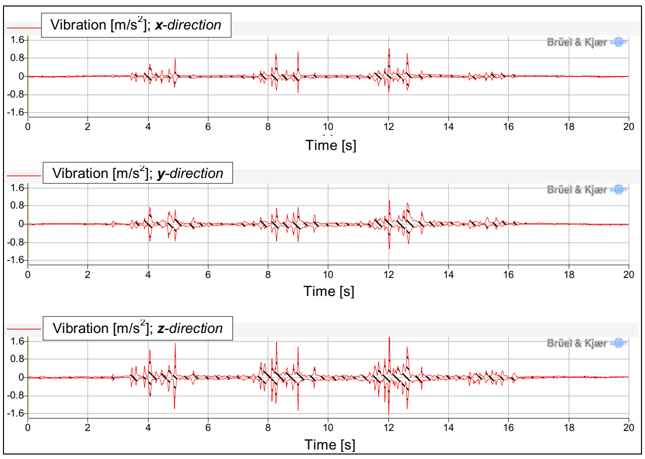


Fig.8 Vibrations during tram TMK 2200 passing.

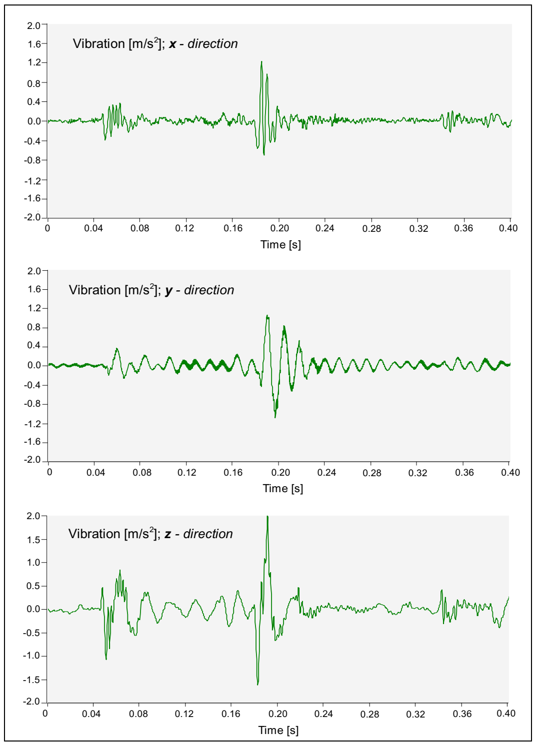


Fig.9 Moments of maximum vibrations (TMK 2200).

The results after reconstruction are shown at the same scales, in order to demonstrate that the vibration frequencies depend on the tram type. For the purpose of vibration intensity assessment, frequency spectra of vibration speeds (1 Hz – 80 Hz) were observed, and that as vibration levels in dB in relation to the referential vibrations 20 nm/s, Figure 12. Vibration spectra were defined at the moments of maximum measured vibrations during the passing of individual trams. On the same spectra, limits of vibration intensity are drawn, which intensity is defined by means of a dimensionless parameter (coefficient K), by which the impact of vibrations on humans in line with DIN 4150 [4, 5] is assessed.

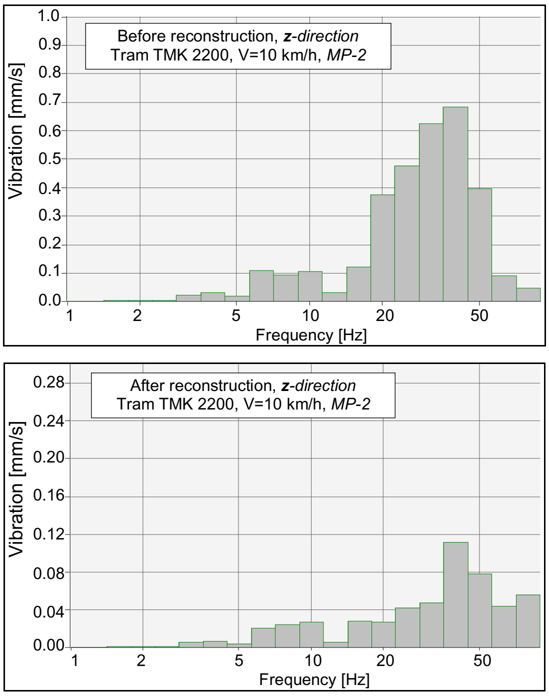


Fig.10 Third-octave vibrations spectra for TMK 2200.

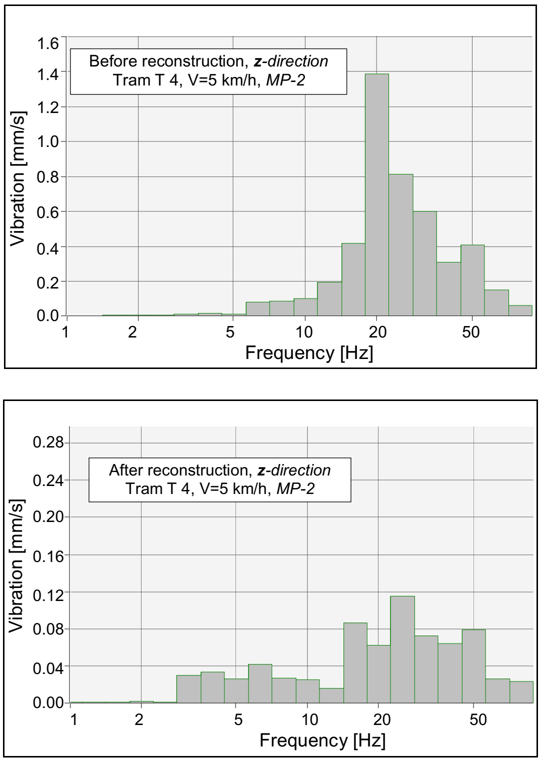


Fig.11 Third-octave vibrations spectra for tram T4.

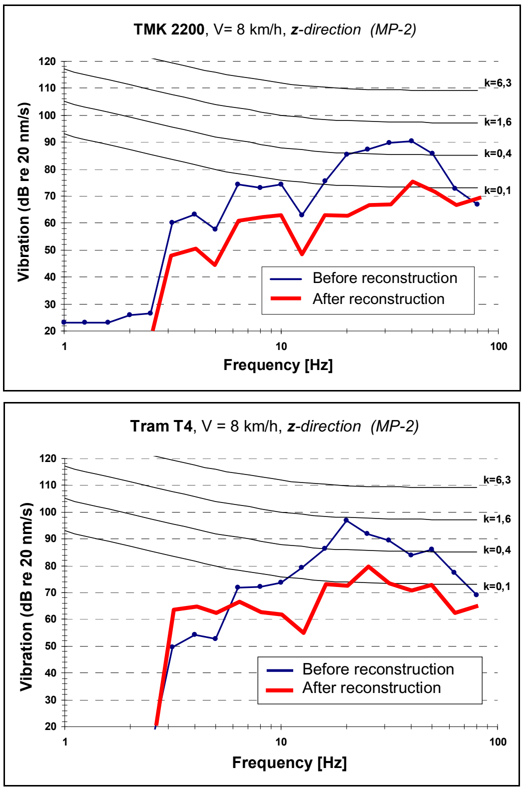


Fig.12 Ground vibrations (measurement in the field).

Analysis and comparison of vibrations in the direction of axis z within the frequency range from 1 Hz to 80 Hz at the moments of maximum measured vibrations for a single tram passing is shown in Table 1. Vibrations caused by tram traffic before reconstruction, on both measurement points, are 'well noticeable' ($0.4<K\leq1.6$). After reconstruction, base vibrations were imperceptible or on the verge of very weak vibrations, [6].

Tram (Measurement point)	Vibrations [mm/s_{RMS}]		Vibration decrease	
	Before reconstr. V_{before}	After reconstr. V_{after}	Amplitude ratio v_B / v_A	Difference [dB] $Lv_B - Lv_A$
TMK 2200 (MP-1)	0.685	0.155	4.42	12.9
TMK 2200 (MP-2)	1.180	0.174	6.78	16.6
T4 (MP-1)	0.902	0.186	4.85	13.7
T4 (MP-2)	1.850	0.216	8.56	18.6

Table 1 Ground vibrations obtained by measuring.

2.3 Measurement of noise

The noise level was measured at a distance of 1.5 m from the tram and on a height of 1.2 m above the ground, in order to get an as accurate as possible impact of vehicle/track interaction on the noise level, Fig. 7. For the analysis of noise levels before and after reconstruction of Jurisiceva – Draskoviceva intersection, peak noise levels were used. The reason is in the fact that equivalent levels depend on the total noise level in the measurement period, and they also contain the noise coming from other participants in the traffic (for instance, motorcycles, personal cars, delivery vehicles, etc.). The peak noise levels appeared because of the passing of tram vehicles on the tracks, and partly also because of the passing of motorcycles and delivery freight vehicles on the road traffic route, which is also visible on the shown noise level diagrams (Figures 13 and 14). Data on maximum values, obtained by the measurement, are statistically processed, and the survey of medium values among the peak noise levels because of tram passing, before and after tram track reconstruction, are visible in Fig. 15.

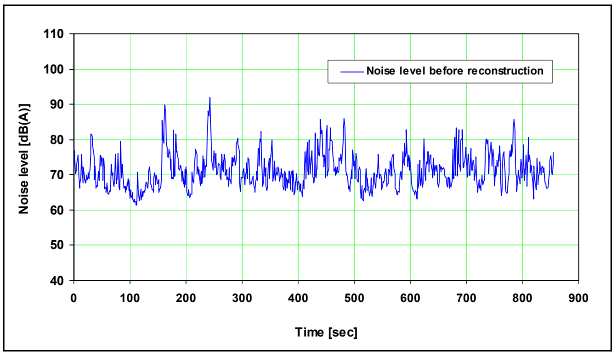


Fig.13 Survey of noise level before reconstruction.

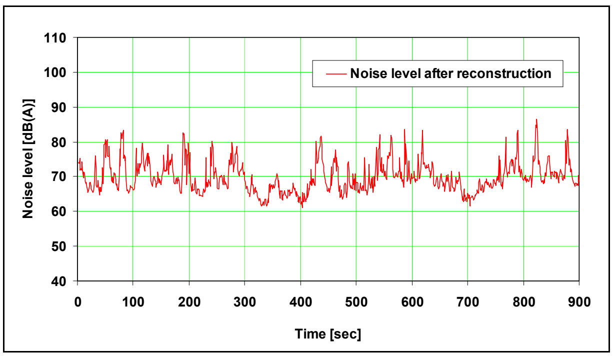
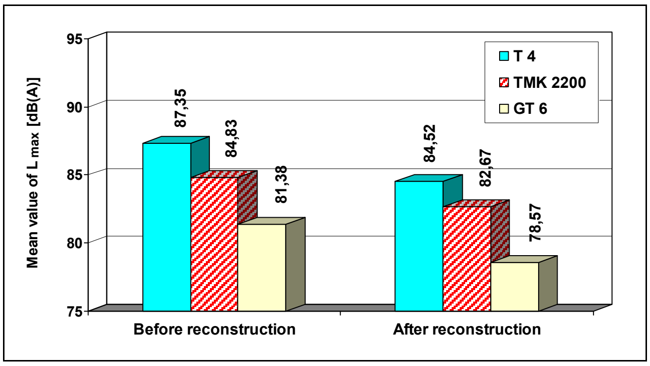


Fig.14 Survey of noise level after reconstruction.



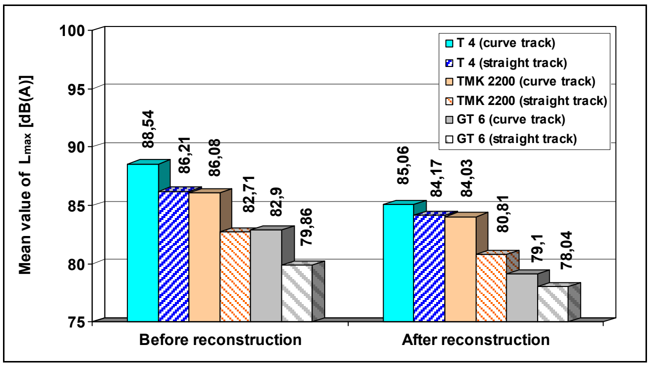


Fig.15 Mean value of maximum noise levels.

As it is visible in the picture, the medium value of the peak noise levels after reconstruction is less than 1.5 to 3 dB(A) in relation to the measurements before reconstruction (on the same measuring point). At the crossing, somewhat less noise decrease in relation to the targeted one of 5 dB(A), which was based on the previous testing on the testing range, was obtained. The reason for a smaller decrease of noise level than the expected one is in the fact that the testing on the testing range was conducted with an impact load, whereas not only the noise coming from wheel impact on the spots of track assemblies and junctions is present during tram passing on the track, but 'squeaking' during vehicle movement on the track, which is curved, [2, 6] also appears. If we observe Jurisiceva-Draskovićeva crossing, the phenomenon of 'squealing' appeared during tram movement in the direction Jurisiceva-Rackoga (direction 1), and Rackoga-Jurisiceva (direction 2), where the radius is 50 m, and especially during tram movement in the direction Jurisiceva-Draskoviceva, where the radius is 20 m (direction 3). During vehicle movement on curves with a smaller radius, lateral wear out of tracks appear, the consequence of which is a larger track width, but also a decreased squealing of the vehicle. After reconstruction, the track geometry (especially the track width) was brought to the proscribed limits, the consequence of which is the appearance of an increased squealing caused by tram movement.

3 Conclusion

The results obtained by the measurement of noise and vibrations on rail intersections with discrete manner of track leaning on the base (before reconstruction works), and after the performed reconstruction and implementation of the continued leaning of tracks on the base, are showing a decrease in noise and vibrations. The levels of vibrations in the vertical direction are decreased from 12.9 to 18.6 dB, which is in full compliance with the targeted decrease of 16.9 dB (decrease achieved at the testing range).

The success in the decrease of vibrations may be described by a comment coming from a female worker at the cash desk of a shop situated only 8 m from the tram tracks: "I don't know what you did with the track, but the cash desk is no longer shaking on the table".

The noise level on the tram crossing was decreased up to 3 dB(A). The magnitude of the decrease depended on the type of the tram, but also on the kind of the track (straight or curved track). With the curved tracks, squealing of the vehicle also appeared which has also heightened the noise additionally, as compared to the case of the vehicles driving over linear tracks.

The favourable results of the continued track leaning on the base have lead to the decision that such a solution related to vibrations decrease should also be applied during the construction of the tracks at Kvatrenikov Square in Zagreb, which was done, too, in July and August 2007. At a length of 430 m' track structure with continued track leaning on the base was executed above the underground garage and above the pedestrian underpass.

References

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