The impact of the geometry of rail welds on noise level in urban environments

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ABSTRACT

Noise is one of the main causes of reduced quality of life, especially in urban environments, where noise is constantly present. Complaints from citizens living and working in urban zones near traffic routes with intense road and tram traffic are more and more frequent. A study on the impact of tram traffic, which is one of the greatest generators of increased noise levels in the City of Zagreb (Croatia), is presented in this paper. According to data from the International Union of Public Transport, tram traffic is much more intense in Zagreb than in other European cities where trams form the backbone of the municipal public transport system. Since the interaction of the wheel and rail has the highest impact on the noise levels, the impact of the geometry of rail welds as a noise contributing factor was studied. Measurements of noise levels were performed in two phases. The first phase addressed noise measurements for tracks with irregularities at the weld zone. The geometry of the irregularities section was first recorded. The second phase involved measuring noise levels at the same locations, but after the irregularities of the rail running surfaces were repaired. The measurements took the tram type and travelling speed into account. That way it was possible to analyse the results to determine to what extent tram type and speed influences increased noise levels. This study was conducted in cooperation with the Zagreb Streetcar Company, the company in charge of reconstruction and maintenance of the tracks in Zagreb. The study results helped to define the impact of the rails running surface geometry in the weld zone on the increased noise levels, and also to determine permissible tolerances for weld geometry on tram tracks in Zagreb.

INTRODUCTION

Reducing traffic noise in urban centres is today the focus of much attention. Were it not, there would be a danger that ambient noise levels would rise to unsatisfactory levels and therefore impact the standard of living. Today, numerous scientists and experts worldwide are working towards reducing elevated noise levels through numerous projects. Due to the large number of parameters which influence noise in traffic noise projects, only a few parameters can be investigated. When the focus of the study is road traffic noise, then the greatest attention is directed at studying the influence of road surface characteristics, types of pneumatics, etc. When investigating rail traffic (trains, trams), attention is focused on studying the irregularity of wheels (wheel flats, unround wheel form) and the influence of rail running surface characteristics (corrugations, rail joints, rail weld geometry) on elevated noise levels. This study addressed the influence of rail weld geometry on noise levels in tram traffic. A tram line in Zagreb was selected for this study, due to its specificity in comparison with other cities in Europe which use the tram as the backbone of the public transportation system. The specificity is in the great traffic volume, with up to 15 million gross tons/year per section, (*Urban Public Transport - Statistics* 1997), with a tram service interval of less than 1 minute, (*Measured traffic volume* 2000). The weld geometry was investigated due to the fact that the contact between wheel-rail has a dominant role in the production of noise and vibration as the tram drives along the rail. Elevated noise levels resulting from tram traffic depend not only on irregularities on the rail running surface, but also on the tram vehicle itself (type, age, driving speed and type of wheel). This paper deals with how the type of tram vehicle influences noise levels. The study was conducted by the Faculty of Civil Engineering University of Zagreb for ZET (Zagreb Streetcar Company), within the framework of the Scientific Project "Permanent way of urban railways", funded by the Ministry of Science and Technology of the Republic of Croatia (Ministry of Science and Technology of the Republic of Croatia 2002).

DESCRIPTION OF FIELD MEASUREMENTS

Measurement site description

The study of the impact of rail weld geometry was conducted on two streets in the City of Zagreb, Ilica Street (Location A) and Maksimirska Street (Location B). These two streets represent the most important links between the western and eastern sections of the city in terms of tram traffic. Reconstruction of the tram tracks was conducted on both streets in 1996. At both locations, tram rails have been placed on a continuous concrete base. The fastening of the rails to the base was conducted with a direct elastic fastening system Zg 3/2 (Figure 1) and the closure of the rails was carried out with reinforced concrete slabs (Figure 2).

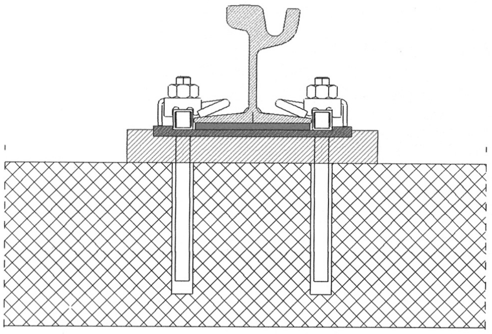

Figure 1. Fastening system Zg 3/2

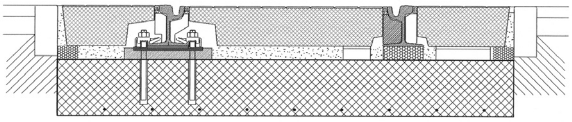

Figure 2. Cross section of tram track in Zagreb

Ilica Street (Location A)

The traffic volume of the tram tracks at Location A totals 14 to 17 million gross tons per annum (MGT), dependent upon the section in question. Research was conducted at two sites on Ilica Street. The first measurement site is open to tram traffic and pedestrian traffic and for delivery vehicles in the early morning hours. The second measurement site is open to both tram and vehicular traffic, primarily cars. A cross-section of Ilica Street is shown in Figure 3.

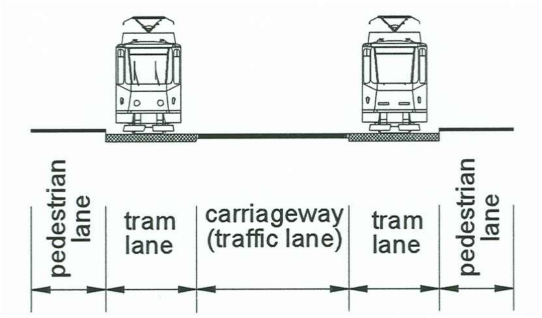

Figure 3. Cross section of Ilica Street

Maksimirska Street (Location B)

The traffic volume of the tram track in Maksimirska Street (Location B) totals approximately 12 million gross tons per annum (MGT), according to data of Zagreb Streetcar Company (*Measured traffic volume* 2000). Unlike Location A, Maksimirska Street is subject to heavy tram traffic as well as a heavy traffic volume of road traffic (cars, trucks, buses). A higher tram speed than Location A is also present here. Maksimirska Street is a four lane road, two lanes for each direction. The tram tracks are situated on the sides of the road and are an integral part of the road lanes. A cross section is shown in Figure 4.

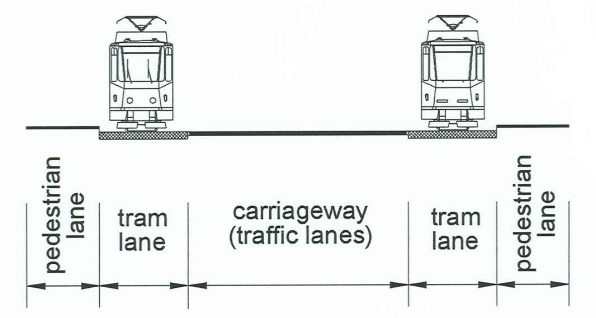

Figure 4. Cross section of Maksimirska Street

Description of the tram vehicles

In measuring noise levels, several types of tram vehicles according to different manufacturers were investigated: Type T4 (Figure 5) manufactured by CKD Tatra, Type TMK 101 (Figure 6) and Type TMK 201 (Figure 7) manufactured by Djuro Djakovic, Type GT6 (Figure 8) manufactured by Düwag and Type TMK 2100 (Figure 9) manufactured by Koncar.

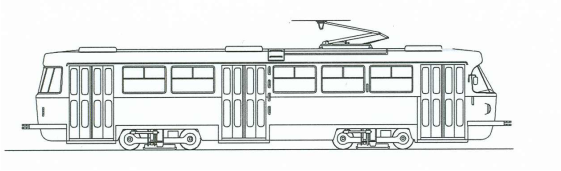

Figure 5. Tram type T4 (CKD Tatra)

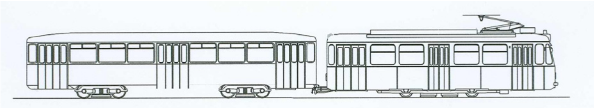

Figure 6. Tram type TMK 101 (Djuro Djakovic)

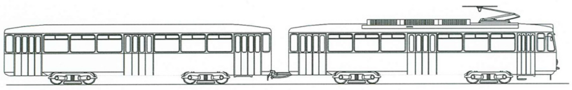

Figure 7. Tram type TMK 201 (Djuro Djakovic)

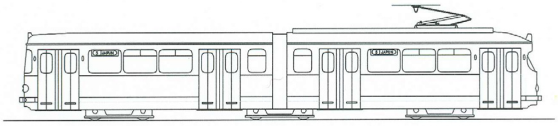

Figure 8. Tram type GT 6 (Düwag)

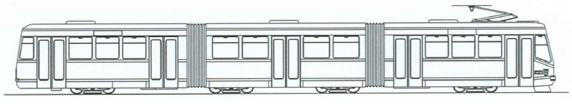

Figure 9. Tram type TMK 2100 (Koncar)

Measuring noise level

Measurements were conducted with the following measuring equipment:

- Precision sound-meter, Bruel & Kjær 2238, serial number 2151881
- Microphone Bruel & Kjær 4188, serial number 2141252
- Protection of microphone wind shield
- Noise level calibrator Bruel & Kjær 4231, serial number 2153238
- Aluminium telescopic stand for the sound-meter.

The software EVALUATOR 7820 by the same manufacturer was used for analysis of measurements.

At each site, noise level was measured for a minimum of five passages of each type of tram vehicle. By measuring the interval of the passage of trams between two fixed points, tram driving speed was determined. All measurements were conducted in favourable weather conditions, with air temperatures from 9 to 12°C, dependent upon the time of day and in wind conditions of 1 to 3m/s. Noise levels were measured one metre from the tram vehicles, at a height of 1.2 metres above the running surface of the rail (Figure 10).

Noise level measurements were conducted in two phases: the first phase (September and October 2004) included noise measurements on tracks with irregularities at the welds, while the second phase (November 2004) included measurements of noise levels at the same locations following repairs to the irregularities of the rail running surfaces.

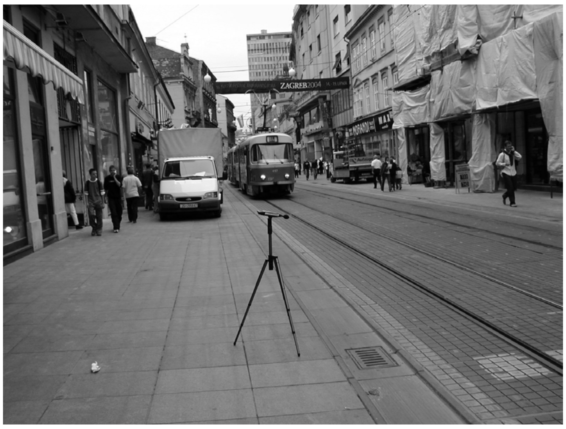

Figure 10. Position of instruments during measuring

Prior to measuring noise levels, the geometry of the rail running surface at rail welds was measured. This measurement was conducted with a profilograph (device for measuring rail unevenness), Figure 11. This device has the capacity of measuring rail running surface irregularities at distances of 18, 23 and 33 mm from the running edge of the rail.

Figure 11. The profilograph – brand name ''CEMAFER''

Considering that the subject of this study are tracks which have been in exploitation for 10 to 12 years, the measurement of unevenness was conducted at a distance of 23 mm from the rail edge, Figure 12a. The reason for selecting this measuring position is based on earlier studies conducted by the Faculty of Civil Engineering of the University of Zagreb, (Lakusic 2003). The differences between the uneven geometries measured at the same measurement location but from varying distances from the rail edge were analysed. It was established that for tracks which are in use for a certain period of time, the differences between recorded unevenness at 23 mm and 33 mm were virtually negligible. The positions of the measurement line of the geometry of the rail running surface in the weld zone (600 mm to the left and right of the weld) are seen in Figure 12a. The weld measurement scale was 1:10 in length and 30:1 vertically, while the instrument error is 0.05mm, (Fastenrath 1977).

Photographs of a weld on the Zagreb tram track and the recorded running surface are seen in Figures 12a and 12b (Location A) and Figures 13a and 13b (Location B). Following measurement of the unevenness geometry, an initial measurement of noise was conducted in the case with unevenness at the running surface (Figure 14a) and following repairs to the unevenness (Figure 14b), noise level measurements were repeated.

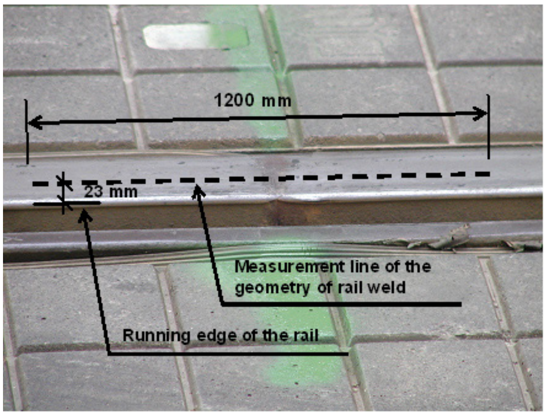

Figure 12a. Picture of weld - Location A

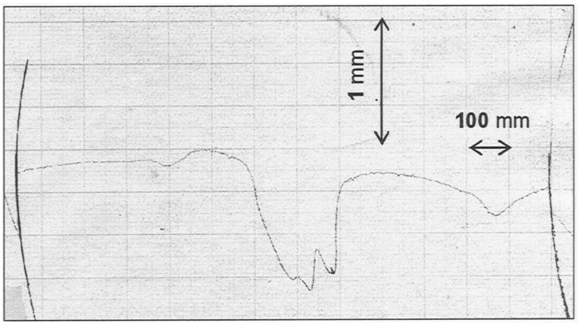

Figure 12b. Vertical weld geometry - Location A

Figure 13a. Picture of weld - Location B

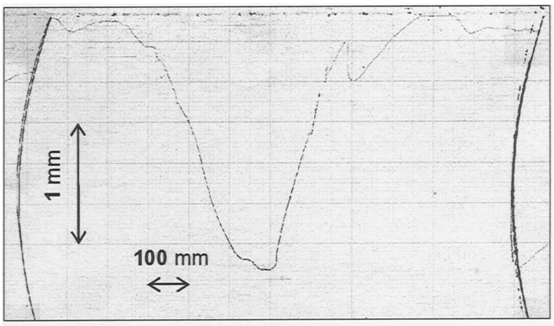

Figure 13b. Vertical weld geometry - Location B

Figure 14a. Unrepaired rail weld – Location A

Figure 14b. Repaired rail weld - Location A

MEASUREMENT RESULTS

Noise levels were measured during tram passby, for a period of 20 to 40 seconds (depending on the tram driving speed). A characteristic depiction of the changes in noise levels over time are shown in Figure 15. The diagram shows the measurement noise levels at the time of passage of two tram vehicles over the irregularity in the rail weld. This diagram clearly shows the passage of each axle of the vehicle over the rail surface irregularity.

The maximum noise levels (peaks) appeared during the passage of tram vehicles, which is evident in Figures 15 and 16a.

Measurements of the tram driving speed show that noise levels largely depend on the driving speed. Reductions in the driving speed of 10 to 15km/h reduced noise levels up to 5dB. Where irregularities on the rail surface are smaller, noise levels during tram passage are also smaller.

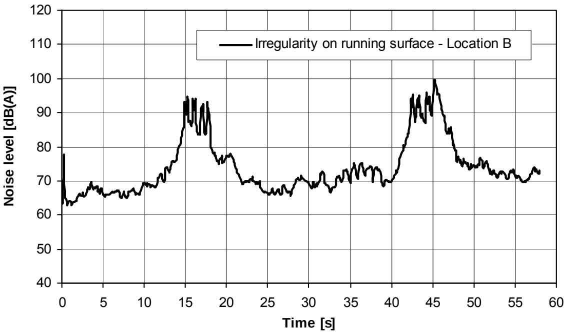

Figure 15. Characteristic depiction of changes in noise level over time

The results of measurements taken at Location A with the presence of irregularity in the rail surface and following repairs to the rail surface are shown on Figures 16a and 16b.

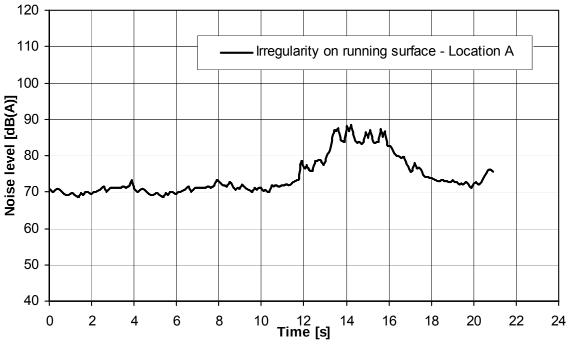

Figure 16a. Noise levels prior weld repairs

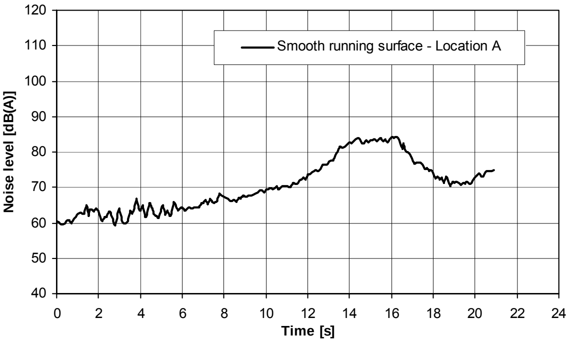

Figure 16b. Noise levels after weld repairs

To assess the impact of rail weld geometry on noise levels, peak noise levels were used. The reason for this lies in the fact that equivalent levels depend on the overall noise levels in the measurement period, and also contain noise from other traffic participants. The results of the peak noise levels were statistically analysed and the mean values of peak noise levels during tram passage on the uneven rail surface and the smooth rail surface are shown in Figure 17.

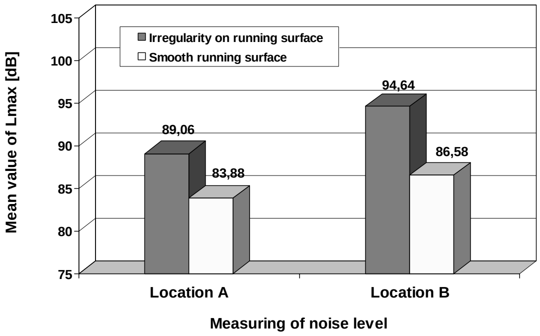

Figure 17. Noise levels prior to and following weld repairs

As is seen in Figure 17, the mean peak noise levels following repairs are 6 to 8dB lower than measurements taken with the presence of rail surface irregularities (at the same location). Comparison of results of measurements prior to and following rail weld repairs at Locations A and B, it is clear that the level of noise at Location A is about 5dB less (prior to weld repairs) and about 3dB less (following weld repairs). The increased noise levels at Location B are due partially to a greater tram speed and partially to greater geometric irregularities. At Location A, dents in the weld were 1.2mm deep, while the same were 2.3mm deep at Location B. The greater depth of irregularities is caused by the strong impact of the vehicle wheel at the moment the vehicle passes over the irregularity and results in a significant increase in noise levels. The increased noise levels (peaks shown in figures) are clearly seen in the characteristic depiction of noise levels over time in Figures 15 and 16. Following repairs to the irregularities, the sudden jumps in the noise level diagrams disappear and the maximum noise levels are thereby decreased (Figure 16b). In addition to comparing noise levels prior to and following repairs to weld irregularities, a comparison was also conducted of the mean values of noise level peaks dependent upon the type of tram. Tram vehicles which passed over the rails which were the subject of this study were investigated, as noted in point 2. The mean values of noise level peaks dependent upon tram type is shown in Figure 18 for the measurement site at Location A and in Figure 19 for the measurement site at Location B.

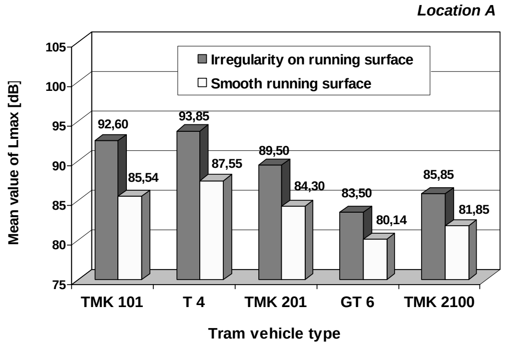

Figure 18. Mean value of maximum noise depending on the tram type – Location A

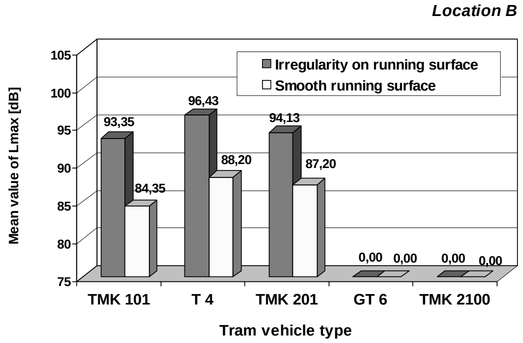

Figure 19. Mean value of maximum noise depending on the tram type – Location B

The comparison of mean values of peak noise levels shows that the passage of the Type GT6 and Type TMK 2100 cause the least noise increase at Location A. There are no trams of these types at Location B, so a comparison of results on various irregular driving surfaces was not possible. At both locations, the Type T4 showed the poorest results considering noise levels which arose at the time of passage, on both rail running surfaces with irregularities and those without irregularities. The noise levels for this type of tram was 3 to 10dB higher than the remaining tram vehicle types, particularly where the rail running surface was uneven.

DISCUSSION

It is evident that irregularities on the rail running surface, particularly with geometrical deviations in weld spots impact many aspects of tram traffic. Through the many years of supervision of reconstruction of the existing tram lines in Zagreb, it was noted that the damage incurred from the passage of vehicles over irregularities is great and that the repairs to damage are expensive and, for the most part, demand a cessation in tram traffic. This partially hinders the flow of road traffic at those locations where the tram tracks are part of the overall road construction, such as the case with the locations that were investigated in this study. It was also established that the greatest amount of damage to both the rail construction and closure elements occur in zones of rail welds. Analysis of the damage which has occurred on tram rails in Zagreb shows that approximately 70% of damages occur at rail weld and composition sites (Lakusic & Rak 2003 p.194, Esveld 2001, p. 561). In the analysis of weld geometry on noise levels, it was found that in irregularities where the vertical deviation is greater than 0.33mm (this listed vertical deviation was analysed at a length of 100mm, meaning that the maximum slope angle is 3.3 mrad), the noise level increased from 1.5 to 10dB in comparison to the smooth running surface. In order to reduce increased noise levels during tram passby on tracks with rail running surface irregularities, it is proposed that the permitted deviation of the rail running surface geometry at weld locations have a maximum slope angle of 3.3mrad. Future studies should include the influence of other types of irregularities on the rail running surface and vehicle wheels on the increase of noise levels during tram movements.

CONCLUSIONS

Measuring noise levels was part of a broader project and is only shown in part in this paper, with the objective of comparing noise levels between tram passages on rail surfaces with and without irregularities. The presence of irregularities in the rail running surface causes not only significant damage to the rail, but also reduces the effect of the rail fastening, impairs the rail geometry, negatively impacts vehicles, reduces passenger comfort and results in an increase in noise levels. The result of measurements on rails with surface irregularities showed that noise level increases ranged from 3 to 10dB, dependent upon the size of the irregularity, type of tram vehicle and travelling speed. In order to reduce the noise levels stemming from rail running surface irregularities, it is necessary to conduct a control of the rail running surface geometry. The systematic monitoring of rail surface geometry, as a function of the passed tonnage, and the permanent repair of damaged spots (particularly at weld sites) can substantially improve passenger comfort and the life of the construction. On tracks with smooth rail running surfaces, not only is noise reduced during passage of tram vehicles, but there is also reduced load on the rails (reduced dynamic impacts), which thereby reduces the costs of rail maintenance.

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