# MONITORING OF SHALLOW-GROOVED TRAMWAY CROSSINGS

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***Resume***

The article presents selected results and the sequencing of research into the project "Long-Term Monitoring of Rail Structures in Tramway Crossings with a Focus on Shallow-Grooved Crossings Aimed at the Optimization of their Maintenance and Noise Reduction", which was running with support from the Technology Agency of the Czech Republic within the Zeta Project (project registration No. TJ04000257) in 2020-2022. The project was elaborated jointly with the Prazska strojirna a.s. Company in cooperation with the Prague Public Transit Company (hereinafter PPTC). The project's objective was to optimize the maintenance of tramway tracks with a focus on shallow-grooved crossings in rail structures taking into account the noise emission levels during the life cycle of these crossings.

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## 1 Introduction

The rail structures installed in tramway crossings are part of tramway tracks loaded by the passage of the tram cars. To a lesser extent, they are also loaded by the passage of road vehicles, which, however, impact more significantly mainly on the track geometry parameters rather than the rail wear. The loading causes the wear of rails and flangeways, as well as the deformation of flangeway bottoms - resulting in the deformation of the prescribed flangeway shape. What seems problematic is, above all, the rail head wear and the lateral rail head loss at the crossings and entering rails, which are directly connected to the crossings. The resulting wear and deformations are affected by the crossing's geometry. The lateral rail head loss is mostly manifested in the branching-off direction, while the rail head wear in the straight direction. Although the rail wear phenomenon in rail structures with shallow-grooved crossings is relatively predictable, the rail profile development over time and the growth of the above deformations have not been validated yet [1-2].

Excessive flangeway wear is connected with the rail head loss in the crossing. It changes the contact area at the wheel-rail interface. Such wear levels also instigate the wheel wear, which is obviously undesirable in traffic operation. Therefore, the flangeway profile is always repaired by welding on new material into the flangeway space after reaching an unacceptable wear level, i.e. the flangeway shape is reprofiled.

The increasing wear of shallow-grooved crossings is associated with development of the noise emission level. The noise emission level changes during the crossing's life cycle - the noise emission around the track grows with the increasing wear of the crossing. The noise emission level is affected not only by the wear, but by the maintenance of shallow-grooved crossings, as well. The crossings are maintained by welding on the missing material and its successive grinding. It has been empirically found and confirmed by measurements that noise emission levels increase (by roughly 4 dB) after the crossing has been welded. Due to traffic, the added material is rolled over and the noise emission level is subsequently stabilized at a lower level again. Like in the above case, it still holds true here that no continuous measurements have been performed so far to match the rail condition with the noise emission arising during the passage of a tram car over the crossing. Nor has the moment been identified when the noise emission is reduced due to the added material rolling over after the crossing was welded [3].

Up to now, the decision about the repair of a shallow-grooved crossing has been made and the interval between individual repairs identified empirically, based on the experience of track administrators. The optimization of the maintenance planning of the rail structures, the grinding plans, flangeway reprofiling and other works on rail structures, should lead to reduced cost and labour requirements. The maintenance planning should be optimized respecting the development of deformations based on the passing loads taking into account the development of the noise emission level. Preventive maintenance campaigns are presumed as well [4].

The stimulus for research into the above issues was made by PPTC during 2019. Nevertheless, as these issues are relatively complex and very extensive to grasp, the project was only oriented towards a part of the whole related field with a focus on shallow-grooved crossings, encompassing just a small range of monitored structures and relationships.

## 2 Definition of terms

In order to describe the project and the phenomena mentioned in more detail, it is necessary to define the terms used and outline the local specifications of the tram operation within which the project was designed.

*Shallow-grooved crossing (crossing with a shallow flangeway)* - a crossing with a reduced flangeway depth so that the wheel flange deliberately travels on the flangeway bottom for some time during the wheel passage over the crossing [5-7].

*Deep-grooved crossing (crossing with a deep flangeway)* - a crossing with such a depth of the flangeway that the wheel rolls on the running surface and there is no contact between the wheel flange and the flangeway bottom of the crossing during the wheel passage over the crossing [5-7].

*Entering rail* - a rail manufactured in the same shape as the corresponding grooved rail, but without the rolled flangeway, which is subsequently milled according to the required geometry [8-10].

Individual tramway networks within the Czech Republic differ in the wheel profile geometry. Therefore, the flangeway depth for a shallow- or deep-grooved crossing has not been precisely defined. The project focused on the tramway traffic operation within PPTC where the shallow-grooved crossings have a flangeway depth of 14 mm. The flangeway width affecting the crossing's geometry depends on the flangeway geometry (straight track x curve). The flangeway in a straight track is 27 mm wide and the flangeway in a curve is 29 mm wide (measured 9 mm below the top of the rail). The crossing is connected to connecting grooved rails with a depth of 39 mm. The height difference is compensated by a 1500 mm long flangeway entering piece. The PPTC network uses the wheel running profile with a width of 86 mm [5].

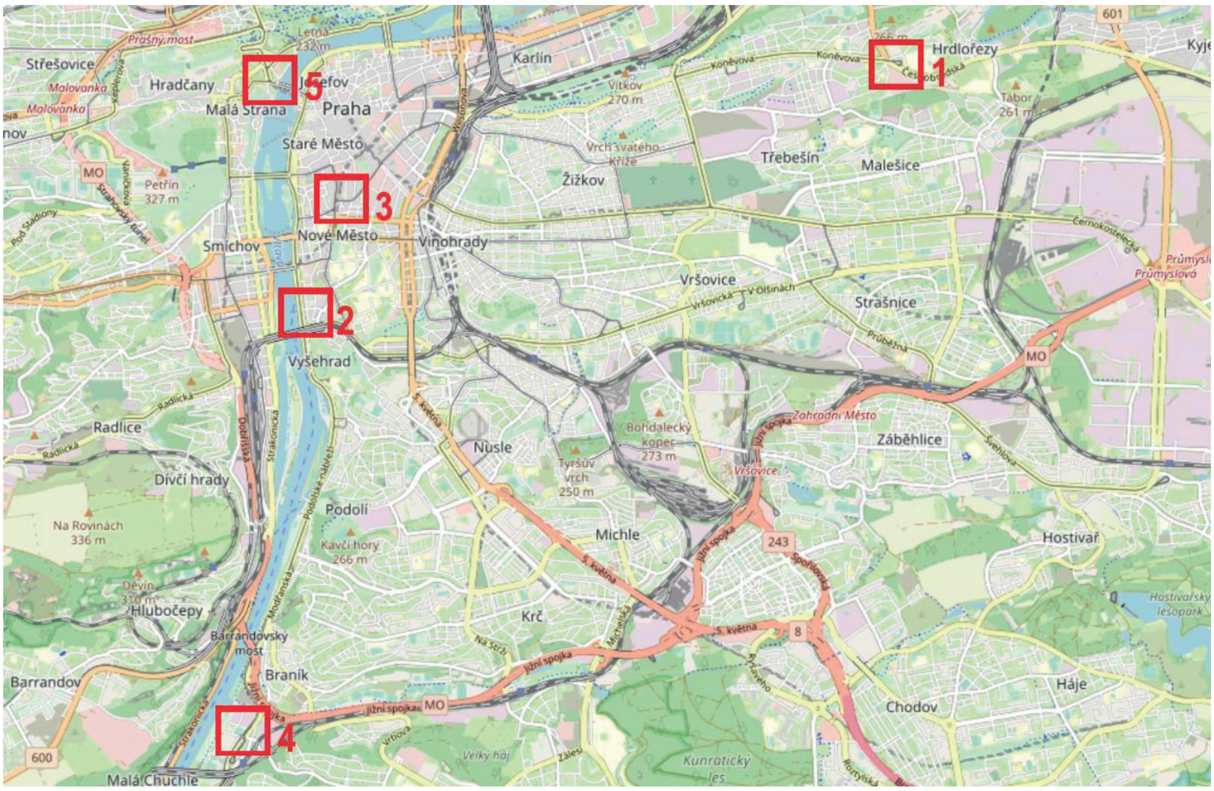


***Figure 1*** *Map of Prague with marked localities monitored within the project: 1 - Spojovaci Terminus; 2 - Rasin Embankment - Svobodova Street junction; 3 - Lazarska - Spalena Street junction; 4 - Junction point to Branik Terminus; 5 - Klarov - Letenska Street junction*

## 3 Project sequencing

The project was elaborated within the PPTC tramway track network from 07/2020 to 06/2022. It was a direct follow-up to the previous pilot academic measurements initiated by the PPTC. The project can be divided into 3 research phases.

In the first project phase, the localities, or rail structures and crossings, respectively, were selected to be continuously and systematically monitored during the project. A total of 5 crossings within the PPTC network were selected, situated in the localities marked on the map below (Figure 1):

- Spojovaci Terminus, specifically the 2nd crossing of the take-off turnout - "Spojovaci" Locality;
- Rasin Embankment - Svobodova Street junction, specifically the crossing in the direction from the centre, to Modrany in the straight direction, or to Albertov in the branching-off direction - "Vyton" Locality;
- Lazarska - Spalena Street junction, specifically the crossing in the direction from Narodni Avenue to Vodickova Street - "Lazarska" Locality;
- Junction point to Branik Terminus, specifically the crossing in the R04 high-speed turnout - "Branik" Locality;
- Klarov - Letenska Street junction, specifically the crossing in the direction from Staromestska to Malostranska Metro Station - "Klarov" Locality.

The crossings in the "Vyton" area and the Spojovaci Terminus had already been monitored prior to the start of the project, from 2019. During that time, the above localities underwent reconstruction and new crossings were installed in the track structures. It was, therefore, possible to monitor the crossings starting from their new, factory condition. The crossings in those localities were monitored systematically over a long time interval - for more than 3 years. This approach is not a common practice in the maintenance of track structures and crossings. It allowed the comparison of the deformation development of a new and repaired (welded) crossing.

The monitoring of the wear and development of individual deformations was carried out using the Contour II measuring instrument (see below). Based on the experience of the PPTC staff, the measurements were carried out at an interval of once a month. After the installation of the structures, or after the flangeway shape reprofiling respectively, the interval was shorter - once every 14 days.

Furthermore, preventive welding of the crossing in the "Vyton" Locality took place during this project phase. This allowed the comparison of the wear and deformations of a new, factory-provided crossing with the crossing welded during the traffic operation. At the same time, the effect of the crossing welding on the noise emission level was observed.

The second project phase involved systematic evaluations of all the measured data and searching for relevant correlations of individual parameters. In particular, these were the correlations enabling the prediction of the crossing's condition - "passing load - rail wear" and "time from repair - rail wear". The noise emission levels of tram car passing over the crossings were continuously measured in two localities: in Branik and Vyton. Both localities had been chosen with regard to possibilities of the noise measurement offered by the spatial layout of the localities, the traffic load of the localities, especially by non-rail traffic and with regard to the noise of the surrounding environment.

In the third project phase, the measured data were evaluated, involving both the data related to the wear and deformations of the crossings and the data related to the noise emissions. During this period, the noise load was matched with the wear development pattern of the crossings and the wear development pattern was correlated with the loading of individual structures.

## 4 Measurement - contour II

Under Regulation No. 177/1995 Coll. of the Ministry of Transport, regular inspections and measurements of railway structures are performed to ensure the operability of tramway tracks. Regular inspections of tramway turnouts in traffic rails are performed on a daily basis. At the same time, tracks are patrolled every two weeks. Based on the recommendation of track supervisors, control measurements of designated sections are made with various instruments (Krab measuring trolley, Contour II.). The measurements within the project were performed with the Contour II measuring instrument (shown in Figure 2) [11-13].

The Contour II measuring instrument is used for checking the PPTC rail wear. It is usually used to check the wear in curves and to check the correct welding of entering rails of shallow-grooved crossings. The instrument measures by means of a red dot laser beam, which is dispersed over the rail and is also imaged by a camera.

The measurement with the Contour II measuring instrument can be divided into 2 types - continuous measurement and spot measurement. Spot measurement reads individual rail transverse profiles, which are defined by the user. Continuous recording captures transverse rail profiles in 3.84 mm or 5.75 mm increments - as selected by the user. The distance between individual points of the transverse profile is 0.13 mm for both continuous and spot recording. The transverse profile width sensed by the instrument is 150-200 mm [1].

The measured data were evaluated in the Contour Eval III programme. Excel was used for the subsequent data comparison to model 2D transverse profiles. The Contour II measuring instrument does not allow

*__Figure 2__ Contour II measuring instrument*

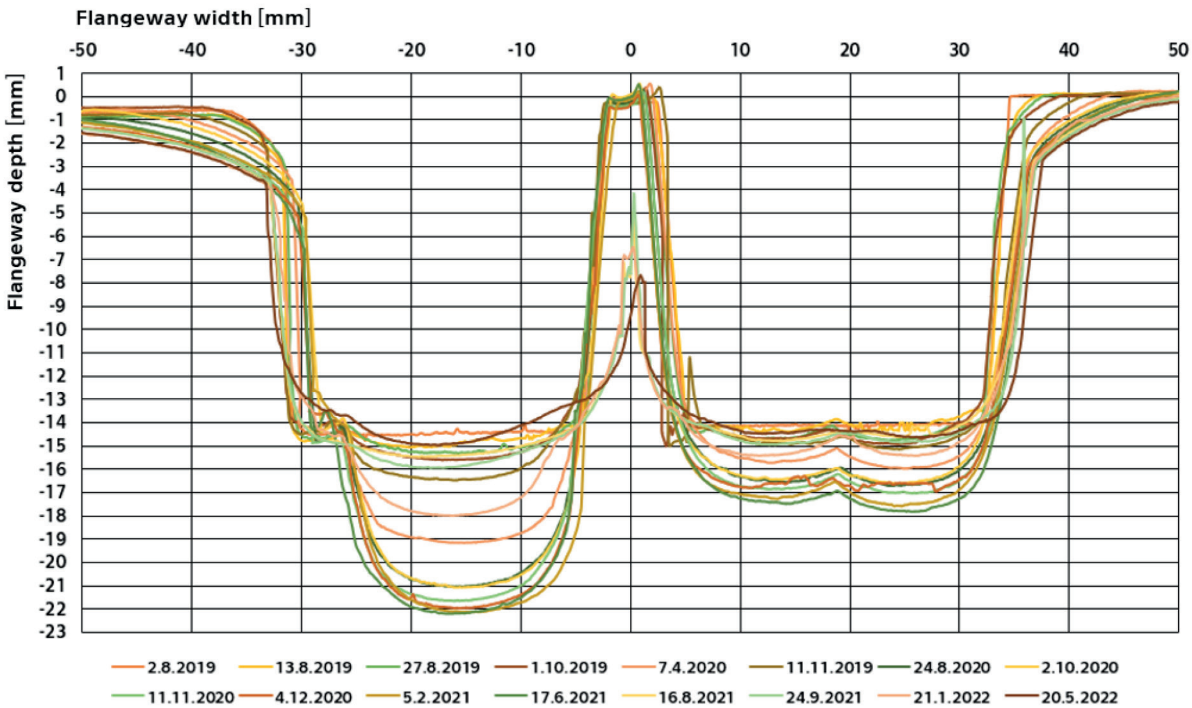


*__Figure 3__ Example of an evaluated profile of the exit nose of a crossing from the rail structure situated at the Rasin Embankment - Svobodova Street junction (Vyton Locality)*

creation of a 3D model as it does not record the track geometry. Using the profiles processed in this way, the development of the wear and deformations over time can be observed (as shown in Figure 3 for illustration). Subsequently, these data can be related to the noise emission level and to the passing load, as well.

## 5 Shallow-grooved crossing: wear and deformation

Crossings with shallow or deep flangeways can be used in tramway structures. Individual operated networks differ in the wheel profile geometry. For this reason, the flangeway depth for shallow-grooved or deep-grooved crossings has not been precisely defined [1, 6].

The use of shallow-grooved or deep-grooved crossings depends, above all, on the wheel profile geometry and the crossing angle of individual rail structures. Therefore, the regulations for the use of shallow-grooved crossings differ for individual networks operated within the Czech Republic. The project is focused on the monitoring of shallow-grooved crossings within the PPTC tramway network, where the wheel profile with a width of 86 mm and a critical crossing angle for the deep-grooved crossing of roughly 12° are used (for a wheel with a width of 100 mm this angle is 16°) [5, 7-9].

Tramway crossings are subjected to wear due to traffic - the flangeways get deeper and wider. The wear of the crossing depends, above all, on the passing load. Thus, a shallow-grooved crossing becomes a deep-grooved one over time. At this point, its maintenance and the flangeway reprofiling are carried out. This is achieved by adding new material into the flangeway by welding. The wear of the crossing is also characterized by deformations of the flangeway bottom. The resulting deformations are mainly dependent on the crossing's geometry. The flangeway in a straight direction is mainly characterized by the flangeway deepening and by the rounding of its edges. The flangeway in a branching-off direction (flangeway in a curve) is deepened due to traffic and a longitudinal edge is formed at the flangeway bottom due to the passage of the wheel flange dividing the flangeway into two parts - the so-called double flangeway is formed. Characteristic defects include the break-off of the crossing's take-off nose.

## 6 Selected results

The wear and deformation development pattern at the crossing in the "Vyton" Locality has been chosen as an example (as shown in Figure 5). In particular, the figure displays the profile in the middle of the crossing where the flangeways in the crossing intersect. For better illustration, a photo with a marked monitored profile is added (Figure 4).

A total of 18 measurements were carried out in the "Vyton" Locality during the project. The results of all the measurements were correlated in one diagram, which shows the time-related development pattern of the wear and deformations, starting from the installation of a new crossing in the structure, including the crossing's flangeway welding (Figure 5).

Figure 5 clearly shows that a vertical flangeway wear from a depth of 14 mm to a flangeway depth of 21.6 mm occurred from the installation of a new crossing (curve of 2.8.2019) to the condition before the crossing maintenance by welding on new material (curve of 17.6.2021). Successively, the flangeway bottom was welded (curve of 30.7.2021) and the flangeway depth was 15 mm. For illustration, see the diagram presenting the respective selected values, Figure 6.

From the above results, it can be concluded that the vertical wear of the crossing over a period of 22 months (from 2.8.2019 to 17.6.2021) was 7.6 mm. On closer examination of the measured results (as seen in Figure 5), it is evident that the wear is slower at the beginning of the crossing's life cycle. Subsequently, the flangeway is deepened more dramatically to a value of approximately 20.5 mm, at which the wear development pattern slows down again. The stabilization of the wear at the end of one life cycle of the crossing (before the flangeway bottom of the crossing is welded) is caused by a change in the contact interfaces between the wheel and the crossing. At the beginning of the life cycle, the crossing is travelled over by the wheel flange. However, the deepening of the flangeway results in the wheel being guided over the crossing on the wheel running surface. Subsequently, the lateral wear, in particular, increases and the vertical wear gradually stabilizes. At this point, the crossing is welded, as the shallow-grooved crossing has become a deep-grooved one, to which the crossing's geometry is not adapted.

In cooperation with PPTC, passing loads were monitored and load counts were carried out on the monitored rail structures. Or, the numbers of passages of individual types of tram cars and trains were monitored, respectively. For the "Vyton" Locality, a total of 850,000 units passed during the period of interest

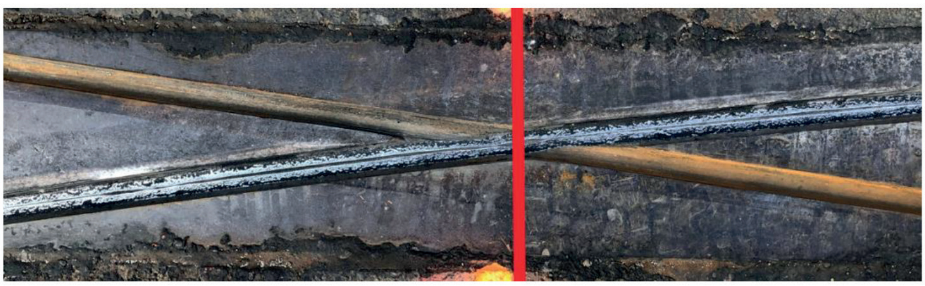

***Figure 4*** *Marked (with a red line) monitored transverse profile of the crossing presented in the article for illustration*

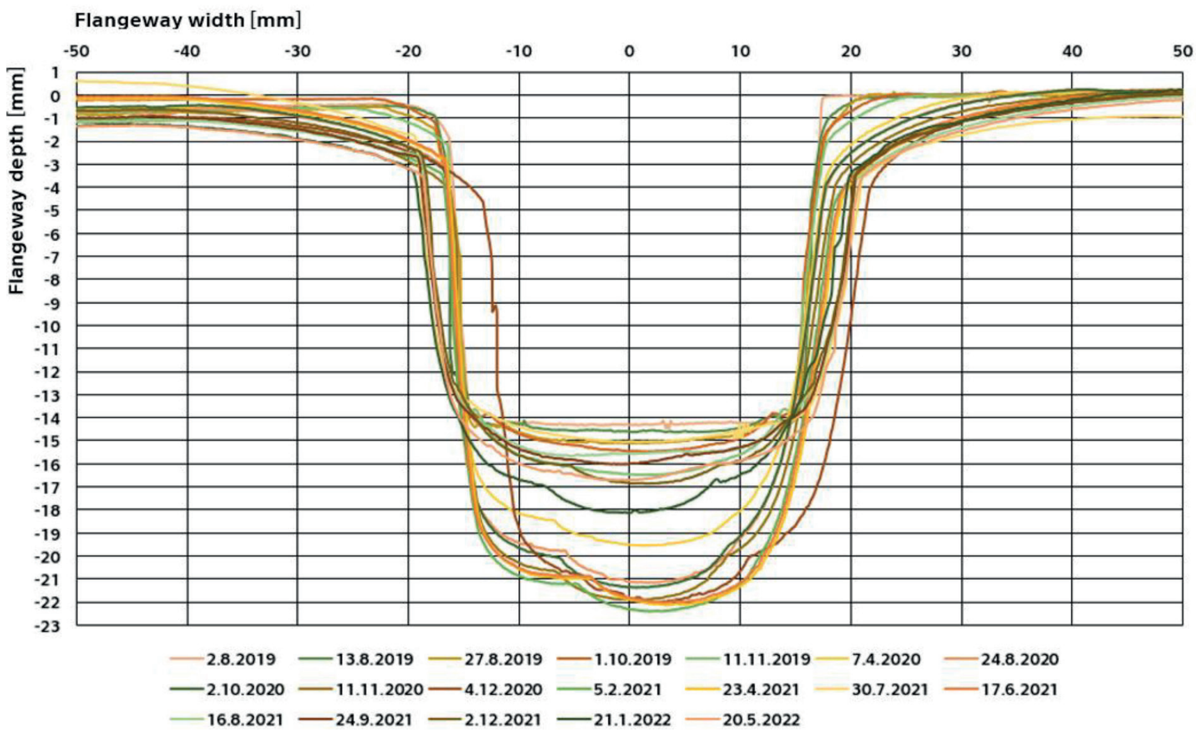


***Figure 5*** *Wear and deformation development pattern of the centre of the crossing in the "Vyton" Locality*

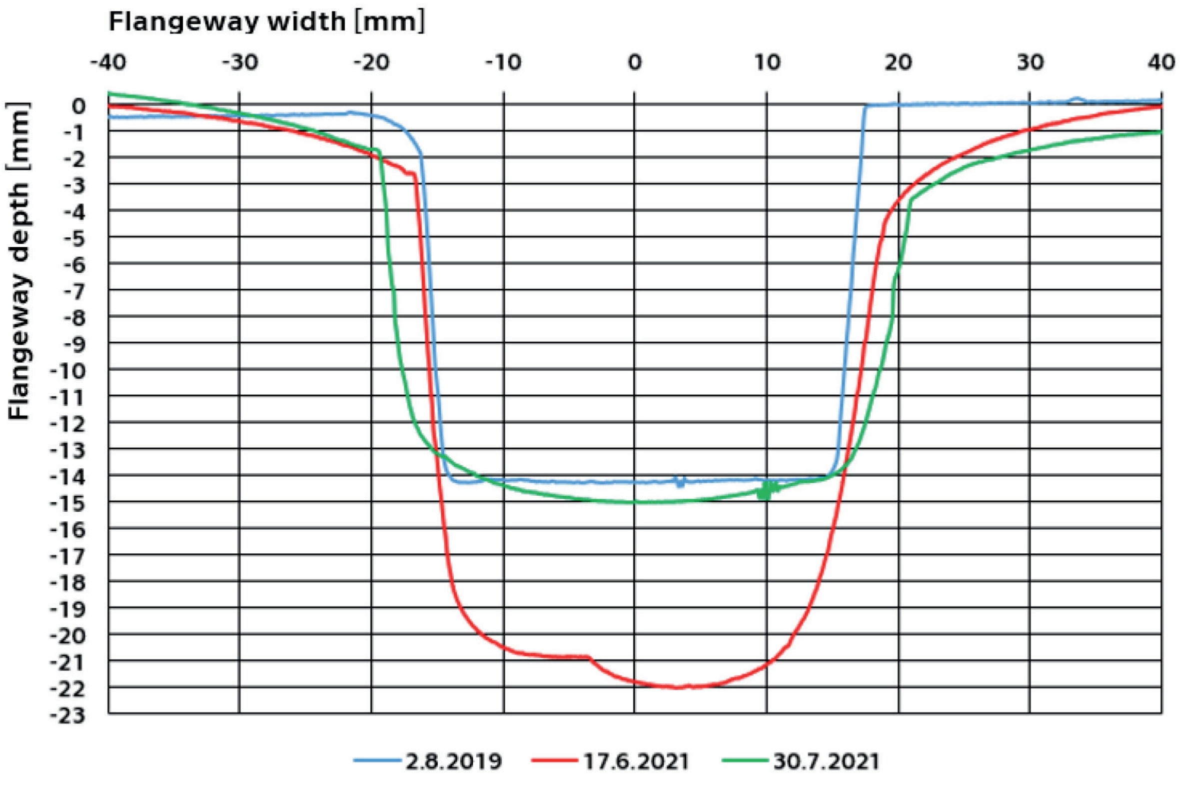


***Figure 6*** *Selected data from measurements in the "Vyton" Locality.*

from August 2019 to June 2021, which represents the passage of approximately 5,600,000 individual axles (combinations of four-, six- and eight-axle cars and trains) and corresponds to a passing load of 40 million tons. This load had caused a wear of 7.6 mm on the crossing. Subsequently, new material was welded into the crossing.

The new material welding (see Figure 7) to the

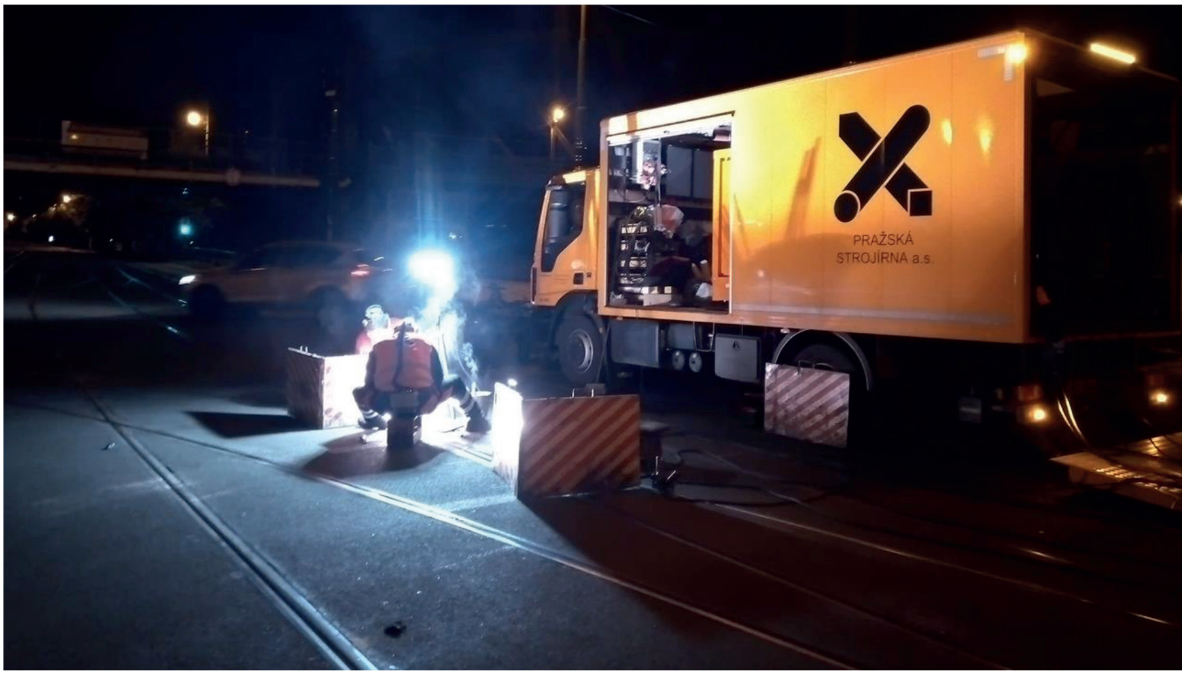


***Figure 7*** *Illustration of welding the flangeway bottom of a shallow-grooved crossing in the "Vyton" Locality. The welding was done with the Weltrode 40 electrode*

bottom of the flangeway takes place during the night operation without a traffic closure. For this reason, the welding is not as precise as factory welding. Even so, there is an effort to weld the material to a depth of approximately 14 mm. Consequently, the depth of a factory-made flangeway (flangeway depth of 14 mm) differs from the depth of the flangeway of a welded crossing (flangeway depth of 15 mm) - this is visible in Figure 6. After the welding on new material, the crossing is finished by grinding and individual weld beads are "smoothened".

## 7 Conclusions

The so-called shallow-grooved crossings undergo vertical flangeway wear during their life cycle. The crossings that were designed as shallow-grooved (travelled on the flangeway bottom) gradually change their profile due to the contact with the wheel and become deep-grooved ones (travelled on the top surface of the crossing). To return the crossing to the original condition, new material must be added by welding it into the flangeway. Excessive wear of the crossings and their flangeways causes a change in the contact interfaces with the wheel. This causes a shift in the contact area between the wheel and the rail, a phenomenon undesirable in traffic conditions as it causes faster wheel wear.

The wear development pattern of crossing depends primarily on the geometry parameters of the crossing (curve radius) and the passing load. The monitored structure experienced a flangeway deepening to the wear limit value (wear at which a shallow-grooved crossing becomes a deep-grooved one) in about 2 years, after approximately 850,000 units had passed over it. Subsequently, the maintenance and reprofiling of the crossing's flangeways was scheduled. By going through this procedure, the crossing enters the second phase of its life cycle, when the whole process is repeated.

The monitoring campaign confirmed the assumptions that the straight flangeways are worn out and deepened in one concentrated track of the passing vehicle wheel flanges, while the curved flangeways are worn out and deepened in two parallel tracks. The wear rate (material loss) corresponds to the passing load - the number of vehicles.

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## Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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