CONTINUOUS WELDED RAIL TRACK ON TRAMWAY BRIDGES

Magdalena Křečková*,[1]

*magdalena.kreckova@fsv.cvut.cz
[1]Faculty of Civil Engineering, CTU in Prague, Thakurova 7/2077, 166 29 Prague 6

Abstract

The issues related to the continuous welded rail remain a debated topic, especially in connection with bridge structures. The issues are relevant not only to railway tracks where bridge structures with long expansion lengths are becoming more and more common but also to tramway tracks. This article presents the continuous welded rail theory on tramway bridges, including an example of a structure on which the monitoring of expansion displacements in rail expansion joints has been initiated.

Keywords

Continuous welded rail track, expansion joint

1 INTRODUCTION

Even though the currently acquired knowledge on the installation of the continuous welded rail on railway tracks is quite extensive, there are still places and constraints that prevent its putting to use and thus, it is necessary to address them in detail when designing a track. These include, for example, structures with different temperature patterns, such as tunnels or bridge structures whose expansion lengths and structural arrangements might compromise the continuous welded rail track's stability. In such cases, rail expansion joints must be installed on one or both sides of a bridge, or rail expansion devices on longer bridge structures with long expansion units. In general, there is a trend to reduce the number of expansion joints to ensure the passengers' comfort, reduce dynamic effects in transition areas and cut the costs of both the installation of the structure with expansion joints and their maintenance. Nowadays, bridge structures are designed with large spans and in a very diverse manner – each bridge structure design is unique. For this reason, it is increasingly necessary to individually access the design of the continuous welded rail on bridge structures and the related design of rail expansion joints. This is why the relationship between the continuous welded rail and the bridge structure remains a continuously discussed topic, not only in the field of railway engineering but also in the design of bridge structures [1].

The issues of the continuous welded rail on bridge structures are relevant not only for railway bridges but are frequently discussed also in connection with tramway bridges which are also designed with large spans. The structural elements on tramway tracks are similar to those used on railway tracks. However, the operation practice has resulted in some specifics that lead to the necessity of verifying or optimising the railway elements, technologies or regulations used, which also applies to the design of bridge structures and associated expansion joints. The differences affecting the design of the continuous welded rail on tramway tracks versus the continuous welded rail on railway tracks are as follows:

- tramway structures are less loaded than railway structures (by more than 50%);
- differences in the structure of the tramway and railway superstructure (use of covering, W-tram structure, etc.);
- the rails used in tramway tracks are generally different (rail cross-sectional dimensions – effect on the magnitude of internal forces);
- directional and gradient conditions of tramway tracks are affected by urban development and roads; etc. [2].

There are significantly more differences between railway and tramway structures; nevertheless, the above-mentioned list proves that although the use of rail expansion joints and the continuous welded rail in railway structures is often discussed, the knowledge gained cannot be fully applied to tramway tracks. Therefore, it is necessary to carry out measurements also on tramway tracks and, based on the results, the functioning of the continuous welded rail on railway and tramway bridges can be compared mutually as well as to the theoretical knowledge.

This article presents the concept of measuring expansion displacements in expansion joints installed on tramway bridge structures located in the network of the Prague Public Transit Company.

Theoretical introduction

Since the beginning of railway construction, superstructure composition has been based on free expansion of rail strings. This has led to ensuring the necessary rail stability, especially with respect to climatic effects (thermal stresses on the track). The length of the rails has been designed to avoid generation of stresses due to temperature loading in the rail. This has resulted in the creation of expansion joints in the rail. Each rail joint is, at the same time, the weakest point of the rail in terms of maintenance, operational safety and vehicle movement smoothness. It is evident that the larger the expansion gap, the greater the dynamic effects acting not only on the superstructure itself but also on the vehicles. Therefore, an effort has been made to eliminate rail joints or, at least, reduce their number. An important contribution in this respect has been the increase in the length of rails and, subsequently, the design of the continuous welded rail structure. Elimination of rail joints reduces operating and maintenance costs of the track by tens of percent [3], [4].

The theory of the continuous welded rail has been studied since its appearance. Transition to continuous welded rail structures was made possible mainly by the improvement of the rail fastening to sleepers, the increase in the cross-section of the rails used and, last but not least, the development of welding technology [3].

The continuous welded rail track is also preferred to the jointed track on bridge structures. The installation of a conventional rail joint is generally ruled out due to the additional dynamic loading of the bridge structure during the vehicle's passage over the joint (dynamic impact generation). On railway bridges, the continuous welded rail track is installed wherever permitted by the Railway Administration's (SŽDC) Regulation S3 Railway Superstructure, Part XII Railway Superstructure on Bridge Structures [5], [6]. In the case of tramway bridge structures, the continuous welder rail track (i.e. welded rails) is also preferred for similar reasons but there is no adequate regulation to follow. The Eurocode provides a description of the interaction between the track and the bridge [7] and the loadings of bridges due to transportation are described. But the Eurocode [7] is not primarily intended for tram bridges but rather just for railway bridges. The design of tram bridges should be based on the rail vehicles used in individual transportation companies. Also, it could be more beneficial to use the basic description given by the Railway Administration's (SŽDC) because it is more understandable for designers of tram tracks.

The installation of the continuous welded rail on bridge structures with an open rail bed is regulated by the same principles as the installation of the continuous welded rail on the track bed. The same rules also apply to bridge construction with no bearings and with a rail bed in a trough. In bridge structures with bearings (with or without a rail bed), the track is laid in accordance with the SŽDC Regulation S3 Part XII Railway Superstructure on Bridge Structures [5], [6].

The structural scheme of a bridge structure is decisive for the installation of a continuous welded rail on the bridge structure. In bridges with bearings, it is the expansion lengths of the load-bearing structures L_T that are the key factor. The expansion lengths of a bridge are classified according to the location of fixed bearings. Bridge structures have one or two expansion lengths, depending on whether the fixed bearing is at the end of the load- bearing structure or between movable bearings. If the fixed bearing is at the end of the load-bearing structure, the bridge structure has one expansion length. Conversely, if the fixed bearing is between the movable bearings, the load-bearing structure has two expansion lengths [6]. If there are more fixed bearings in the structure, the bridge structure may have more than 2 expansion units. The maximum permissible expansion lengths L_T of load- bearing bridge structures for laying the continuous welded rail are listed in the table below (Fig. 1). In the case of longer expansion lengths, individual solutions are required. This also applies to selected bridge structures where measurements in the track and the bridge structures have begun,showing the real values of the movement of the continuous welded rail strings and the bridge structure, depending on temperature changes of the air or the bridge, respectively.

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Case No.	Arrangement of bridge bearings and expansion length L_T	Rail shape	Bridges with load-bearing structures of: steel, with rail bed sleepers, timber	steel, with rail bed sleepers, concrete	steel, with bridge sleepers, supported centrically	steel, with bridge sleepers, directly seated	steel, with direct rail laying	steel concrete, with rail bed sleepers, timber	steel concrete, with rail bed sleepers, concrete	conc[rete], with ra[il bed] slee[pers], timber
1	L_T	R65	125	90	70	23	20	160	120	180
		UIC 60	110	80	66	23	20	140	103	156
		T,S 49	85	60	60	23	20	100	70	110
2	L_{T1} L_{T2}	R65	125	90	70	23	20	160	120	180
		UIC 60	110	80	66	23	20	140	103	156
	L_T L_T	T,S 49	85	60	60	23	20	100	70	110
3	L_T L_T L_T	R65	125	86	70	25	23	160	110	180
		UIC 60	108	74	63	25	23	136	93	153
	unlimited number of structures	T,S 49	75	51	50	25	23	90	60	100
4	L_T L_T	R65	65	46	35	19	17	100	70	110
		UIC 60	61	44	35	19	17	86	61	96
		T,S 49	55	40	35	19	17	60	45	70

Fig. 1 Table: maximum admissible expansion lengths L_T of load-bearing bridge structures for laying the continuous welded rail [6].

The effects of climatic conditions on the continuous welded rail with full tension (in the part without the possibility of expansion – the middle part of the continuous welded rail) are manifesting themselves by a change in the temperature of the rail strings. This causes a change in the internal forces (or internal stresses) in the rail. The magnitude of the change in the internal force is proportional to the magnitude of the change in the rail temperature. Hooke's law is used to determine the change in the respective value. At the same time, the change in the internal force in the rail depends on the size of the cross-sectional area of the rail (1):

$$P = \alpha \times \Delta t \times E \times F \quad (1)$$

where α is the thermal expansion coefficient of steel (0.000012 K^{-1}), Δt is the temperature difference, E is the modulus of elasticity and F is the cross-sectional area of the rail. For the rail 49E1, a profile without head wear, the magnitude of the axial force generated by a change of 1 °K equals 14.82 kN. In the breathing ends of the continuous welded rail (in the outermost parts), changes in the length of the rail strings are prevented mainly by resistances against the rail displacement in the fastenings or in crossovers. The resistance to the rail displacement in the fastening, if properly assembled, must reach a minimum value of 7 kN in the fastening [4]. The longitudinal resistance in the rail fastening is greater than the longitudinal resistance in the rail bed. The potential displacement occurs in the rail fastening to the sleeper (not the entire track skeleton is displaced). The total movement at the end of the continuous welded rail (i.e. in the end expansion joint) depends on the total resistance to rail displacement, the temperature difference with respect to the fastening temperature of the rail string and the cross-section of the rail profile. The prescribed fastening temperature ranges within +17 °C to +23 °C [5]. Due to climate changes and exposure to sunlight, temperature of the rail strings can vary between -30 °C and +60 °C. Based on these data, the theoretical force from the continuous welded rail (not bridge) acting in the bridge closure and the movement in the expansion joint at the end of the continuous welded rail (i.e. in the rail expansion joint) can be calculated. The latter is determined from the relationship (2):

$$\Delta l = \frac{\alpha^2 \times E \times F}{k_p} \times \int_{t_0}^{t_{max}} (t - t_0)\,dt \quad (2)$$

where α is the thermal expansion coefficient of steel, $(t-t_0)$ is the maximum temperature difference, t_{max} is the maximum temperature, E is the modulus of elasticity, F is the cross-sectional area of the rail and k_p is the rail resistance in the fastening [1], [4]. The above formula is simplified and does not consider movement of the bridge structure. Thus, the movement of the bridge structure must be added.

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2 METHODOLOGY

An individual solution can be found on selected tramway bridges which have been chosen for measuring expansion displacements in rail expansion joints. In total, 3 bridge structures in the network of the Prague Public Transit Company were selected, namely the Troja Bridge, the Barrandov Bridge and the bridge between the Palmovka – Ohrada tram stops (hereinafter the Palmovka – Ohrada Bridge). All the above localities are marked on the following map (Fig. 2). Due to the scope of the article, the measurements on only one of the bridge structures, namely the Palmovka – Ohrada Bridge, are be described below.

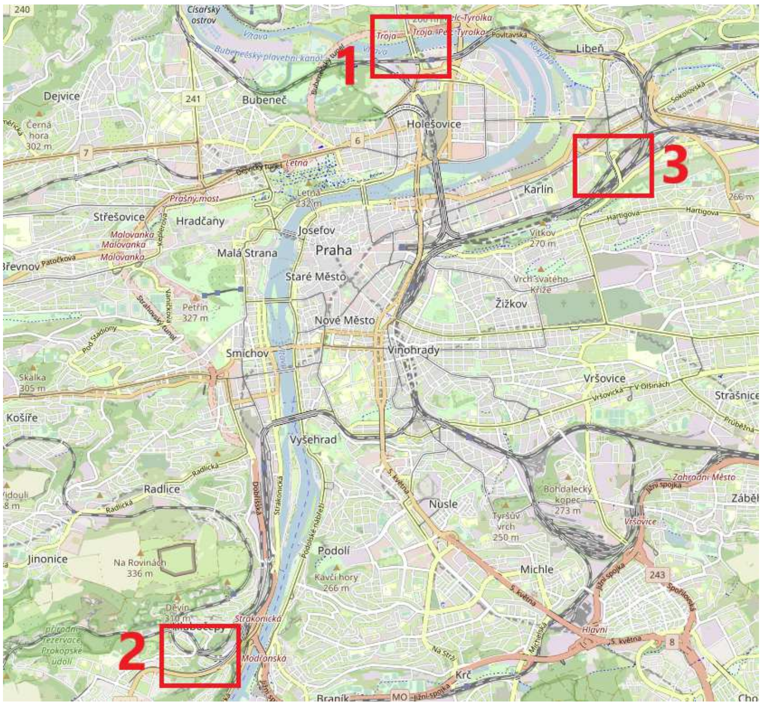

Fig. 2 Position of the monitored bridge structures in the network of the Prague Public Transit Company.
1 – Troja Bridge; 2 – Barrandov Bridge; 3 – Palmovka – Ohrada Bridge.

The measurements on the Palmovka - Ohrada Bridge started in the summer of 2023 and will continue in the following years. The design speed in the monitored section is v = 50 km/h (in the case of a lack of the 130 mm elevation gain, v_{130} = 60 km/h). The track on the bridge is led in 4 directional curves. The gradient ratios on the bridge vary from 7.4‰ to -6.34‰. The length of the bridge is approximately 455.449 m. The load-bearing structure is supported by 12 piers, out of which 2 piers, roughly in the middle of the structure, have a fixed bearing (longitudinal expansion movements are prevented in 1 span). The expansion lengths are 196 m and 214 m.

A continuous welded rail on concrete sleepers in the rail bed in the trough is laid on the bridge. The load-bearing bridge structure is a prestressed concrete box girder with 12 spans. The tramway superstructure consists of 49E1 rails, W14 elastic fastening, concrete sleepers of the ŽPSV B03 DP01 var. 2 type, the sleeper spacing in the track is 0.35 m. The rail bed thickness is at least 325 mm below the bottom rail string. Inner guard rails are placed along the entire length of the bridge. Rail expansion joints are located at both ends of the bridge in the directional curve with an elevation gain. On the southern side of the bridge (closer to the Ohrada tram stop), the expansion joints are placed in the left-hand curves with radii R = 250.55 m and an elevation gain D = 80 mm (Rail No.1), and R = 254.05 m and an elevation gain D = 80 mm (Rail No.2). On the northern side of the bridge (closer to the Palmovka tram stop), the expansion joints are placed in the right-hand curves with radii R = 254.05 m and an elevation gain D = 76 mm (Rail No.1), and R = 250.55 and an elevation gain D = 76 mm (Rail No.2). On the southern side of the bridge, the rail expansion joints are placed at a longitudinal slope of 7.4‰. On the northern side of the bridge, the rail expansion joints are placed at a longitudinal slope of -6.23‰. The maximum displacement of the tongue rail in the rail expansion joint is ±100 mm. The length of the expansion joints is 9.85 m, and they are mounted on oak sleepers. The continuous welded rail was laid on the bridge at a fastening temperature of 23 °C.

Two mutually independent methods were chosen for measuring the movement of the tongue rail in the expansion joint to ensure the continuity of the measured data in case of damage to the measuring base. The measurements were scheduled to begin in the summer of 2023 (due to high temperatures) and continue during the subsequent seasons depending on the air temperature conditions.

The first method for measuring the mutual position of the knee and the tongue rail chosen was the measurement with a steel gauge attached to the knee rail web (Fig. 3). The tongue rail, overlapping the steel gauge, shows the current value on the steel gauge. During the installation of the steel gauge, the value was read and further used as a reference value. At the same time, the temperature of the rail was measured (at the rail head) which was also established as a reference value for further measurements. During the next measurements, a new value on the steel gauge was always recorded. The difference between the actual value and the reference value indicates the displacement in the rail expansion joint. At the same time, the temperature of the rail was always measured.

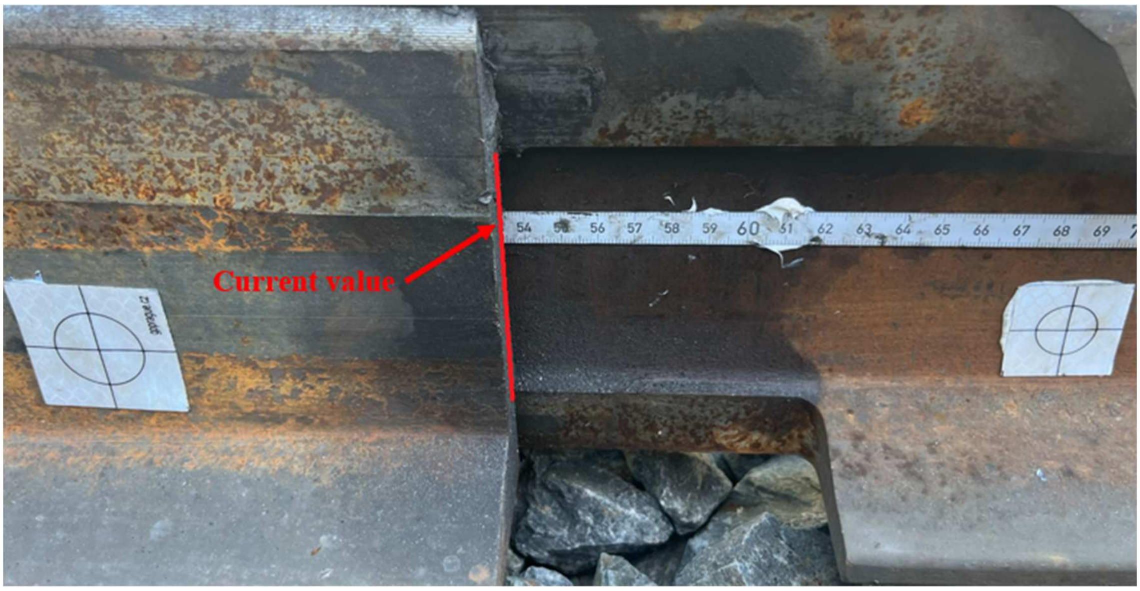

Fig. 3 Marking of the first measurement method of the mutual position of the tongue and the knee rail.

The second method consisted in marking fixed points on the rail string webs using reflective surveying labels with a cross marked on them to measure the mutual position. Similarly to the first case, their relative position was measured during installation and this value was established as referential. Mutual position of points is measured using a sliding caliper and a carpenter´s square. The edges of the carpenter's square are depicted in the following image as red lines (Fig. 4). The measurement method is schematically illustrated in the following picture (Fig. 4). During each subsequent measurement, the mutual position of these points was measured again. The difference between the measured values and the reference value once again expresses the displacement in the rail expansion joint.

Fig. 4 Marking of the second measurement method of the mutual position of the tongue and the knee rail.

In the past, such measurements were carried out by drilling holes in the rail strings. This method could not be used (despite its higher probability of long-term preservation) as this is a newly reconstructed section (reconstruction completed in June 2023). Both measurement methods can be clearly seen in the figure below (Fig. 4).

To compare the movement of the bridge structure, similar fixed points were marked on the structure using reflective labels which represent an additional measurement base. The first point was placed on a part of the bridge structure above the pier. That bridge structure does not undergo expansion. The second point was placed on the expanding section of the bridge structure. The depiction of the placement of measuring points is shown in the following picture (Fig. 5). Once again, their mutual position was measured using a steel gauge.

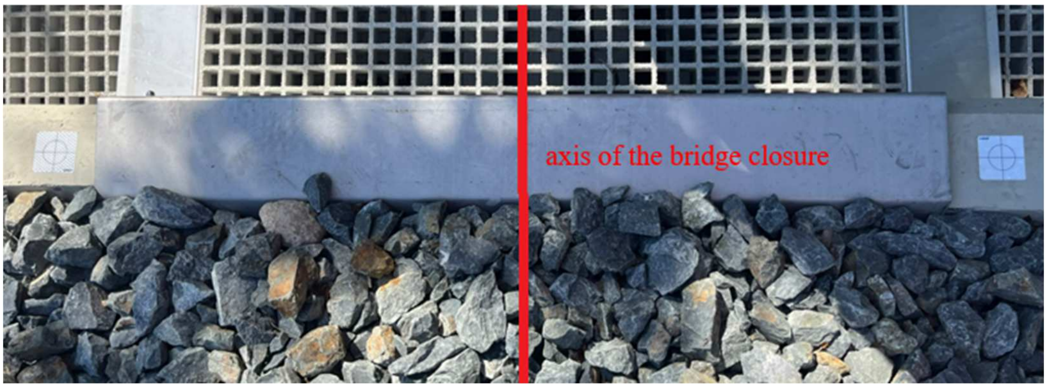

Fig. 5 Marking of measurement method of the expansion movement of the bridge structure.

The measurements also record the current temperature of the air, the rail strings and the bridge structure (at its top and bottom surfaces). The mutual movement of the sleepers and the bridge structure was neglected at this phase of the monitoring campaign. This measurement methodology is used in all the mentioned locations.

3 RESULTS

Right now, the results from the measurements are not representative as the volume of the data collected is too small. All the selected bridge structures will be monitored using the measurement methods described above. When the data set is large enough for a statistical evaluation of the measurements, individual values will be compared with theoretical calculations. In the next phase of data evaluation, the model of the structure will be solved as a 1D model consisting of two co-acting elastic elementary parts - the rail string and the bridge structure including the rail bed, sleepers and fastening. Based on the values obtained, the value of the specific resistance to displacement will be identified.

During each monitoring campaign, the movement in the rail expansion joint (using the methods described above), the movement of the bridge structure, air temperature, rail temperature and the temperature of the top and bottom surfaces of the bridge structure are measured. For example, the following table (Tab. 1) presents data measured on August 24, 2023 at the Palmovka – Ohrada bridge.

Tab. 2 Example of measured data on August 24, 2023 at the Palmovka – Ohrada bridge. “Movement – rail expansion joint 1” represents the first measurement method (using steel gauge). “Movement – rail expansion joint 2” represents the second measurement method (mutual position of points – reflective surveying labels). “Movement – bridge” represents the mutual position of the points on the bridge.

Measurement	**24. 8. 2023**
Time of measurement	*15:30*
Temperature – air	*28.7 °C*
Temperature – rail	*49.7 °C*
Temperature – top surface of the bridge	*43.2 °C*
Temperature – bottom surface of the bridge	*29.3 °C*
Movement – rail expansion joint 1	*44.3 cm*
Movement – rail expansion joint 2	*34.90 cm*
Movement – bridge	*138.5 cm*

4 DISCUSSION

Due to the small amount of data, it is not yet possible to present comprehensive results from the measurements. The measurements will continue during different seasons. Each measurement will be compared with theoretical calculations. The structure model will be processed as a 1D model consisting of two components – continuous welded rail and bridge. The results will be compared both with theoretical calculations and with values obtained from other locations.

5 CONCLUSION

The envisaged aim of the on-going measurements is the comparison of the measured values with theoretical values and, at the same time, comparison between the individual localities. Subsequently, it should be determined if there is a relative movement of the track skeleton and the bridge structure due to temperature changes. The data obtained (bridge temperature, rail temperature, rail displacement values at the breathing end) will be used to calculate the value of the specific resistance to displacement relative to the bridge structure, which, however, cannot be compared with the value used for the resistance to rail displacement in the fastening (the effect of the tramway superstructure composition). Furthermore, directional conditions, which are quite complex on the Ohrada – Palmovka Bridge, could be incorporated in the computation model to further refine it. Finally, the track skeleton components could be expediently used in the model to examine individual resistances to the displacement in more detail.

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