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QUANTITATIVE ANALYSIS OF ADDITIONAL TEMPERATURE STRESSES IN CONTINUOUSLY WELDED RAILS: INFLUENCE OF BRIDGE EXPANSION LENGTH

Summary: In this paper, the influence of bridge expansion length on the distribution of additional temperature stresses in continuously welded rails is investigated. Using a representative railway viaduct as a case study, the effects of thermal interaction between the track and the bridge are analyzed. The research focuses on the design phase, particularly on the definition of bridge expansion lengths through the arrangement of bridge supports, i.e., the position of fixed and movable bearings, which directly determine these lengths. Numerical models of thermal track/bridge interaction were developed to quantify additional temperature stresses in rails for different bridge expansion lengths. The results show that shorter expansion lengths lead to lower additional temperature stresses, whereas longer expansion lengths result in higher stresses. The obtained findings enable the optimization of track structure design on bridges, contributing to safer and more reliable operation of continuously welded rails on railway bridges.

Keywords: railway track, continuously welded rails, track/bridge interaction, bridge expansion length, temperature stresses, numerical modeling

KVANTITATIVNA ANALIZA DODATNIH TEMPERATURNIH NAPONA U KONTINUALNO ZAVARENIM ŠINAMA: UTICAJ DILATACIONE DUŽINE MOSTA

Rezime: U ovom radu istražen je uticaj dilatacione dužine mosta na raspodelu dodatnih temperaturnih napona u kontinualno zavarenim šinama. Na primeru reprezentativnog železničkog vijadukta analizirani su efekti termičke interakcije između koloseka i mosta. Fokus istraživanja je na fazi projektovanja, pri definisanju dilatacionih dužina mosta kroz raspored oslonaca, odnosno položaj pokretnih i nepokretnih ležišta, koji direktno određuju ove dužine. Numerički modeli termičke interakcije kolosek/most razvijeni su radi kvantifikacije dodatnih temperaturnih napona u šinama pri različitim dilatacionim dužinama mosta. Rezultati pokazuju da kraće dilatacione dužine dovode do manjih dodatnih temperaturnih napona, dok veće dilatacione dužine izazivaju njihovo povećanje. Dobijeni zaključci omogućavaju optimizaciju pri projektovanju konstrukcije koloseka na mostu, doprinoseći sigurnijoj i pouzdanijoj eksploataciji kontinualno zavarenih šina na železničkim mostovima.

Ključne reči: železnički kolosek, kontinualno zavarene šine, interakcija kolosek/most, dilataciona dužina mosta, temperaturni naponi, numeričko modeliranje

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1. INTRODUCTION

Continuously welded rails (CWRs) represent the standard solution in modern railway infrastructure due to their numerous advantages, including improved ride comfort, reduced maintenance requirements, and enhanced structural continuity. However, the elimination of rail joints leads to the development of significant longitudinal stresses in the rails, primarily caused by temperature changes. These stresses become particularly complex and critical on railway bridges, where the interaction between the track and the bridge structure generates additional effects that must be carefully considered during the design phase.

Track/bridge interaction is governed by the combined response of the rail, fastening system, ballast, and bridge structure under various loading conditions, including thermal actions, traffic loads, and braking or acceleration forces. Among these, temperature effects play a dominant role, especially in CWRs, where restrained thermal expansion and contraction generate considerable additional stresses. On bridges, these effects are further amplified by the independent thermal behavior of the bridge superstructure, which interacts with the track through longitudinal resistance mechanisms.

One of the key parameters influencing the magnitude of additional temperature stresses in CWRs on bridges is the bridge expansion length. This parameter, defined by the position and arrangement of fixed and movable supports, determines the extent of longitudinal thermal displacements of the bridge structure. Longer expansion lengths generally result in larger thermal displacements and higher additional rail stresses, while shorter expansion lengths tend to reduce these effects. Therefore, the appropriate definition and optimization of expansion length during the design phase is of great importance for ensuring the safety and serviceability of the track/bridge interaction system. A detailed investigation of this topic is presented in the doctoral dissertation by Mirković [1]. In this paper, selected parts of that research are presented, focusing on the sensitivity analysis of additional temperature stresses in CWRs on bridges with respect to the bridge expansion length.

Early research on track/bridge interaction under temperature effects was conducted by Frýba [2], who developed an analytical approach for solving thermal track/bridge interaction problems. He proposed a theoretical formulation for CWRs on bridges subjected to temperature actions, taking into account the linear longitudinal stiffness of the connection between the track and the bridge. The analytical model was validated through experimental investigations, and recommendations were provided regarding permissible bridge expansion lengths for railway bridges carrying CWRs.

Subsequently, Ruge and Birk [3] introduced a nonlinear formulation of track/bridge interaction, enabling a more realistic analysis of longitudinal forces in CWRs on bridges. Their work marked a significant advancement in understanding the complex mechanical behavior of the coupled system. Further contributions by Strauss et al. [4] demonstrated that the stress state in CWRs on bridges is influenced not only by thermal deformations of the bridge structure but also by the mechanical characteristics of the rail fastening system. In addition, De Backer et al. [5] investigated in detail the possibility of omitting rail expansion devices in CWR tracks on bridges, providing important insights into conditions under which such solutions are feasible. More recently, Zhang et al. [6] proposed advanced track/bridge interaction models aimed at facilitating the design of long-span railway bridges with CWRs.

From the perspective of technical regulations, the UIC Code 774-3 [7] provides comprehensive guidelines on track/bridge interaction, defining limit values for additional stresses and displacements in CWRs on bridges, as well as permissible bridge expansion lengths in relation to the use of rail expansion devices. Furthermore, the European Committee for Standardization (CEN) has published the standard EN 1991-2 [8], which covers actions relevant to the design of railway bridges and includes provisions for track/bridge interaction in accordance with UIC recommendations. At the national level, the Institute for Standardization of Serbia has adopted the Serbian versions SRPS EN 1991-2 [9] and its National Annex SRPS EN 1991-2/NA [10], ensuring alignment with European standards.

Current design standards prescribe limit values for allowable stresses and displacements and define conditions under which special measures, such as rail expansion devices, must be implemented. Nevertheless, there is a need for a more detailed quantitative understanding of how bridge expansion length influences additional temperature stresses, particularly for different structural configurations and boundary conditions.

In this context, the objective of this paper is to investigate the influence of bridge expansion length on the distribution and magnitude of additional temperature stresses in CWRs. The study is based on numerical modeling of track/bridge interaction using a representative railway viaduct as a case study. Special attention is given to the role of support arrangement and structural configuration in defining expansion length and its impact on rail stress levels. The results aim to contribute to the optimization of bridge and track design, providing practical guidance for achieving safer and more reliable railway infrastructure systems.

2. DEFINITION OF BRIDGE EXPANSION LENGTH

The bridge expansion length is defined as the distance from the thermal center, i.e. the point that remains stationary under temperature changes, to the free end of the bridge structure. It represents the effective length over which longitudinal thermal expansion and contraction occur within the bridge system. The position of the thermal center depends on the arrangement and stiffness of the bridge bearings and supports, meaning that bridges with similar overall dimensions may exhibit different expansion lengths depending on their structural configuration.

In track/bridge interaction analysis, the expansion length is a fundamental parameter that reflects the effective structural length governing the thermal deformation response relative to the thermal center. Therefore, it plays a crucial role in the assessment of temperature effects in railway bridge design and track/bridge interaction analysis.

Figure 1 illustrates the principles for determining bridge expansion lengths (L_T) for different structural systems.

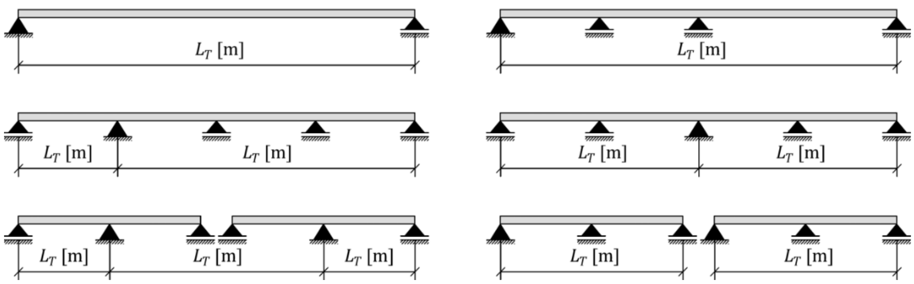

Figure 1: Bridge expansion lengths for different structural systems according to [7]

For bridges designed as simply supported girders in a series, the expansion length is equal to the span length, i.e., the length of an individual simply supported superstructure. In this case, thermal displacements occur relative to the fixed support, while the movable support allows longitudinal displacement, resulting in a single, clearly defined expansion length.

For bridges with continuous girder systems, the expansion length is defined as the distance between the fixed bearing and the end movable bearing of the bridge structure. Since the fixed bearing restrains longitudinal displacement, it represents the reference point of the thermal center, while all thermal expansion and contraction develop relative to this point. Consequently, the magnitude of longitudinal displacements at the bridge ends increases with increasing expansion length.

When the fixed bearing is located within the bridge structure rather than at the end support, two separate expansion lengths are formed, extending from the fixed bearing toward each end of the bridge. In such cases, thermal displacements occur in both longitudinal directions relative to the fixed support. On the other hand, when the fixed bearing is positioned at one end of the bridge, only a single expansion length exists, and the entire bridge structure expands or contracts in one longitudinal direction.

The maximum bridge expansion lengths requiring verification through track/bridge interaction analysis for bridges carrying CWRs (without a rail expansion device installed in the track on the bridge) are defined as follows [7]:

- 60 m for steel bridge structures with ballasted track, where the maximum total bridge length with a single fixed bearing located at the center may reach up to 120 m,
- 90 m for concrete and composite bridge structures with ballasted track, where the maximum total bridge length with a single fixed bearing located at the center may reach up to 180 m.

Based on the bridge expansion length and the results of the track/bridge interaction analysis, a decision is made on whether a rail expansion device should be installed on the bridge. Rail expansion devices are generally located above the end movable bearing when the calculated additional rail stresses and/or relative displacements between the bridge structure and the track exceed the prescribed limit values. In addition, installation is required when daily temperature variations cause bridge expansion or contraction exceeding the allowable displacement limits, typically ranging from 10 to 15 mm [7].

The primary purpose of the rail expansion device is to accommodate relative longitudinal displacements between the bridge superstructure and the CWRs, thereby allowing thermal expansion and contraction of the bridge while reducing the transfer of additional temperature stresses to the CWRs.

Figure 2 presents the distribution diagram of total temperature stresses in CWRs on a bridge equipped with a rail expansion device.

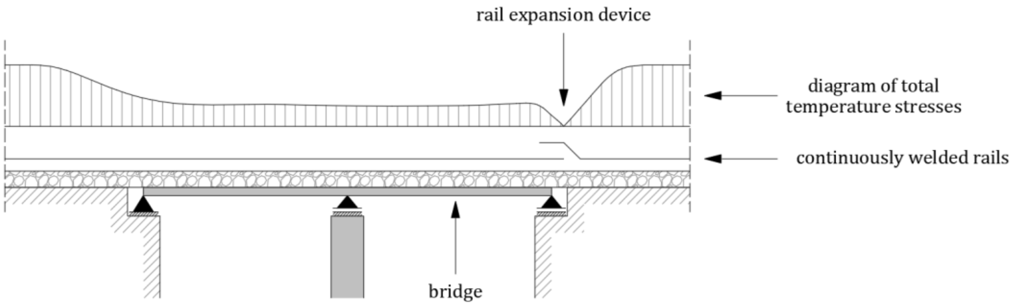

Figure 2: Schematic representation of the distribution of total temperature stresses in CWRs on a bridge with an installed rail expansion device according to [11]

From a practical engineering perspective, the optimization of fixed and movable bearing arrangements is not only a structural issue but also a key factor affecting CWR performance. Designers should aim to minimize expansion lengths where feasible, while still meeting the structural and functional requirements of the bridge. This integrated approach can reduce the need for additional mitigation measures, such as rail expansion devices, and enhance the overall durability and serviceability of railway systems.

3. NUMERICAL MODEL OF TRACK/BRIDGE INTERACTION

In this case study, a track/bridge interaction analysis was carried out to investigate the influence of bridge expansion length on the magnitude of additional temperature stresses in CWRs on a bridge structure consisting of simply supported concrete girders arranged in 10 × 30 m spans (total length 300 m). A numerical model for the analysis of track/bridge interaction was developed using the Midas Civil software [12].

Figures 3 and 4 present the numerical model used for the track/bridge interaction analysis.

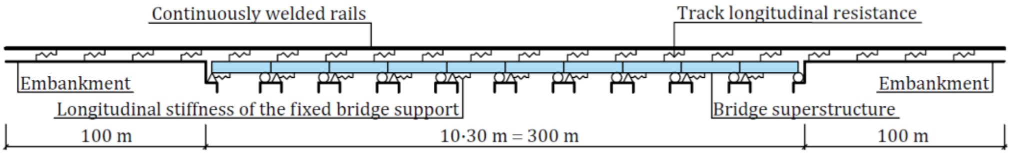

Figure 3: Numerical model for track/bridge interaction analysis

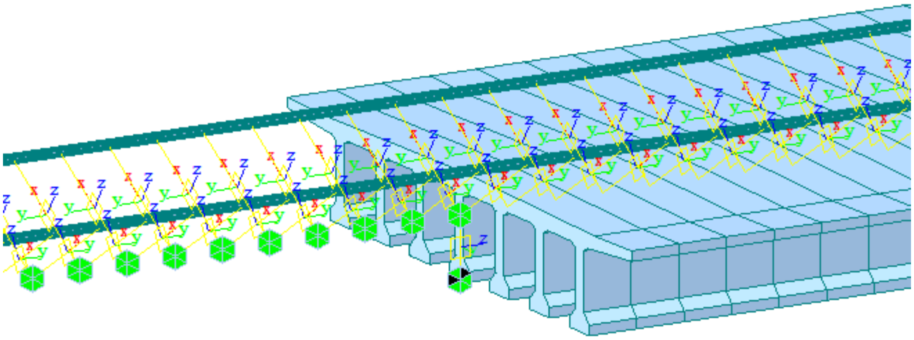

Figure 4: Detail of the numerical model for track/bridge interaction analysis with connection elements between the track, bridge, and embankment

Table 1 presents the characteristics of the numerical model used for the track/bridge interaction analysis, including the track and bridge parameters, as well as the applied loading conditions.

Table 1: Characteristics of the numerical model for track/bridge interaction analysis

Track parameters	
Rail profile type:	60E1
Rail steel grade:	R260
Longitudinal resistance of the unloaded track (summer conditions):	20 kN/m, 2 mm (limit relative displacement)
Longitudinal resistance of the loaded track (summer conditions):	60 kN/m, 2 mm (limit relative displacement)
Longitudinal resistance of the unloaded track (winter conditions):	30 kN/m, 0.5 mm (limit relative displacement)
Longitudinal resistance of the loaded track (winter conditions):	60 kN/m, 0.5 mm (limit relative displacement)
Bridge parameters	
Number of tracks on the bridge:	2 (double-track bridge)
Bridge structural system:	simply supported concrete girders in a series
Spans and total bridge length:	10·20 m = 200 m, 10·25 m = 250 m, 10·30 m = 300 m
Bridge expansion lengths:	20 m, 25 m, 30 m
Arrangement of bridge supports:	F (fixed) - M (movable)

Longitudinal stiffness of the fixed bridge support:	200000 kN/m
Geometrical characteristics of the bridge superstructure:	A = 8.40 m^2 (cross-sectional area) I_{yy} = 3.80 m^4 (moment of inertia about the Y-axis) I_{zz} = 82.60 m^4 (moment of inertia about the Z-axis) h = 2 m (height of the bridge superstructure) W = 2.5 m (width of the bridge superstructure)
Material properties of the bridge superstructure:	C 40/50
Loading conditions	
Temperature change in the bridge superstructure:	+35 °C (summer conditions) –35 °C (winter conditions)
Acceleration/braking of a railway vehicle on the bridge:	33 kN/m (≤ 1000 kN) (acceleration) 20 kN/m (≤ 6000 kN) (braking)
Axle load of a railway vehicle on the bridge:	LM71 (load model)

4. RESULTS AND DISCUSSION

Figures 5 and 6 present the results of the track/bridge interaction analysis and the values of additional temperature stresses under summer and winter conditions, depending on the bridge expansion length.

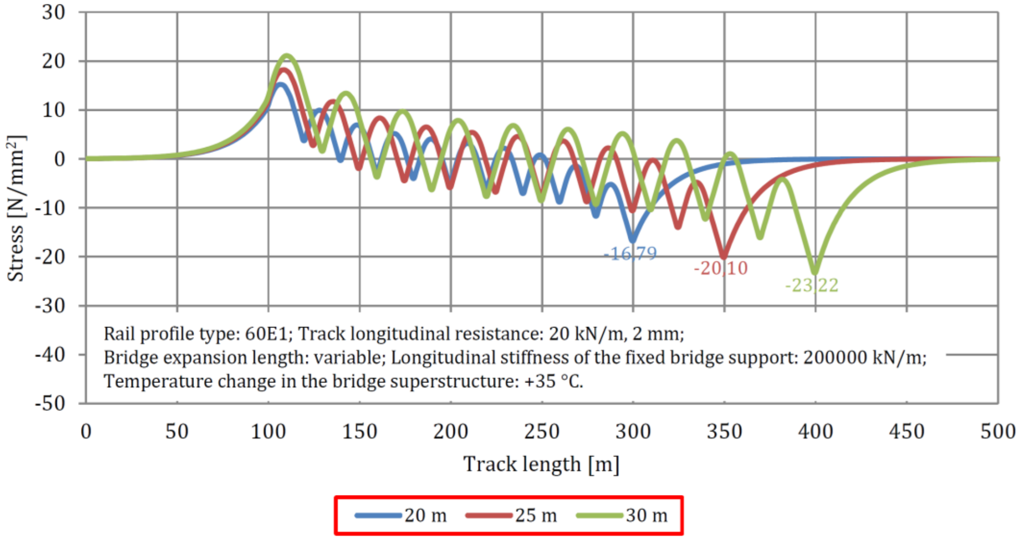

Figure 5: Additional temperature stresses as a function of bridge expansion length under summer conditions

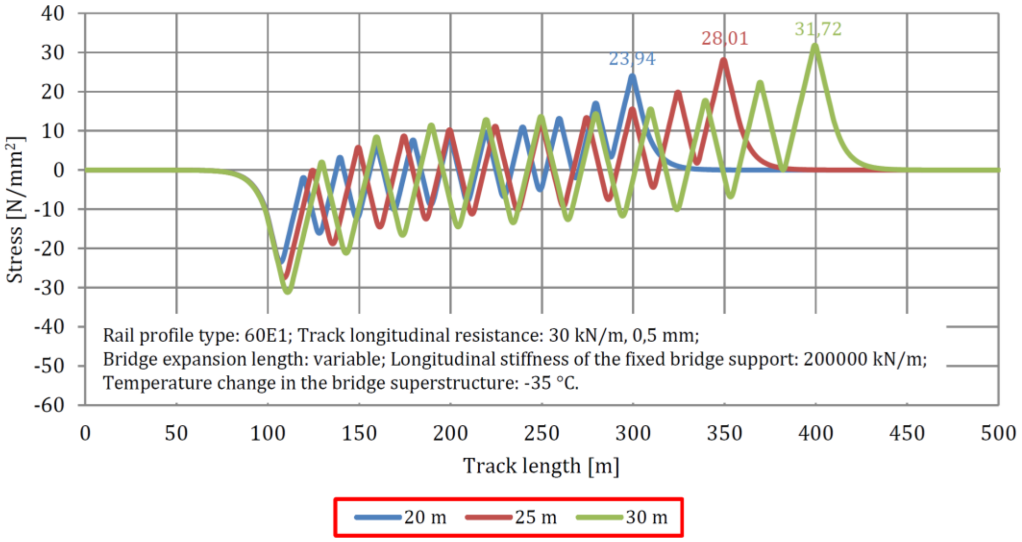

Figure 6: Additional temperature stresses as a function of bridge expansion length under winter conditions

In the analysis, a rail profile of type 60E1 was used. For summer conditions, a track longitudinal resistance of 20 kN/m was adopted for a limit relative displacement of 2 mm, while for winter conditions, a track longitudinal resistance of 30 kN/m was adopted for a limit relative displacement of 0.5 mm. The longitudinal stiffness of the fixed bridge supports amounts to 200000 kN/m. The analysis was carried out for temperature changes in the bridge superstructure of +35 °C in summer conditions and −35 °C in winter conditions.

Table 2 presents the maximum values of additional temperature stresses depending on the adopted bridge expansion length, as well as the percentage reduction in these stresses with decreasing expansion length. The obtained results indicate that, in the case of reducing the bridge expansion length by 10 m, additional temperature stresses can be reduced by 6.43 N/mm² (27.69%) in summer conditions and by 7.78 N/mm² (24.53%) in winter conditions.

Table 2: Maximum values of additional temperature stresses as a function of bridge expansion length

Bridge expansion length	Additional temperature stresses (summer conditions) [N/mm²]	Additional temperature stresses (winter conditions) [N/mm²]	Reduction of additional temperature stresses (summer conditions) [%]	Reduction of additional temperature stresses (winter conditions) [%]
30 m	–23.22	31.72	/	/
25 m	–20.10	28.01	–13.44	–11.70
20 m	–16.79	23.94	–27.69	–24.53

The observed reduction of up to approximately 28% with a relatively small decrease in expansion length (10 m) indicates a pronounced sensitivity of the system. This suggests that even minor adjustments in the structural configuration during the design phase can lead to large benefits in terms of stress reduction.

From the structural behavior perspective, shorter expansion lengths limit the cumulative longitudinal displacements of the bridge superstructure induced by temperature changes. As a result, the relative displacements transferred to the track are reduced, leading to lower interaction forces and consequently smaller additional stresses in the CWRs. Conversely, longer expansion lengths allow greater thermal displacements, which intensify the interaction between the bridge and the track, increasing the risk of exceeding permissible stress limits.

It is also important to highlight the difference in behavior between summer and winter conditions. Although the percentage reductions are comparable, the absolute stress reductions differ, reflecting variations in track longitudinal resistance and boundary conditions. In winter conditions, the higher longitudinal resistance results in a stiffer track response, leading to slightly lower relative percentage reductions, while still producing significant absolute stress decreases. This emphasizes the importance of considering seasonal variations in the design and assessment process.

Furthermore, the results underline the importance of track longitudinal resistance parameters. The adopted values of longitudinal resistance and limit relative displacement directly influence the distribution and magnitude of additional stresses. Therefore, accurate characterization of ballast and track behavior is essential for reliable modeling and safe design.

5. CONCLUSIONS

The conducted research clearly demonstrates that additional temperature stresses in CWRs on bridges are significantly influenced by the bridge expansion length. The results of the numerical analyses confirm that reducing the expansion length is an effective and practical strategy for mitigating these stresses. This reduction can be achieved during the design phase through an optimized arrangement of fixed and movable bearings, or by modifying the structural concept of the bridge, such as shortening the bridge structure and increasing the length of the approach embankments.

Quantitatively, the study shows that a reduction of the bridge expansion length by 10 m can lead to a decrease of up to 28% in additional temperature stresses in CWRs for the analyzed case of simply supported concrete girders arranged in 10 × 30 m spans (total length 300 m). This finding highlights the strong sensitivity of rail stresses to bridge structural configuration and confirms the importance of integrated track/bridge design.

From a broader engineering perspective, the results emphasize that the interaction between track and bridge must be carefully considered in early design stages to ensure structural safety, serviceability, and long-term performance. Optimizing expansion length not only reduces the risk of excessive rail stresses and potential track instability but also contributes to improved maintenance conditions and operational reliability of railway infrastructure.

Overall, this study provides a valuable contribution to the understanding of track/bridge interaction and offers a clear, quantitatively supported pathway for optimizing the design of bridges carrying CWRs.

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REFERENCES

[1] Mirković, N. Prilog numeričkoj analizi osnovnih i dodatnih temperaturnih napona u kontinualno zavarenim šinama, Doktorska disertacija, Građevinski fakultet Univerziteta u Beogradu, 2023.

[2] Fryba, L. Thermal interaction of long welded rails with railway bridges. Rail International. 1985. 16: 3.

[3] Ruge, P., & Birk, C. Longitudinal forces in continuously welded rails on bridgedecks due to nonlinear track–bridge interaction. Computers & structures. 2007. 85:7-8. p. 458-475.

[4] Strauss, A., Šomodíková, M., Lehký, D., Novák, D., & Bergmeister, K. Nonlinear finite element analysis of continuous welded rail-bridge interaction: monitoring-based calibration. Journal of Civil Engineering and Management, 2018, 24:4. p. 344-354.

[5] De Backer, H., Outtier, A., Ferdinande, B., Schotte, K., & Mys, J. Application limits for continuously welded rails on temporary bridge decks. Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit. 2017. 231: 4. p. 482-497.

[6] Zhang, J., Wu, D., Li, Q., & Zhang, Y. Experimental and numerical investigation of track-bridge interaction for a long-span bridge. Structural Engineering and Mechanics. An Int'l Journal. 2019. 70: 6. p. 723-735.

[7] UIC Code 774-3 (R). Track/bridge Interaction. Recommendations for calculations. Paris, France. 2001.

[8] CEN/TC 250. EN 1991-2:2003/AC:2010. Eurocode 1: Actions on structures - Part 2: Traffic loads on bridges. Brussels, Belgium. 2010.

[9] SRPS EN 1991-2. Evrokod 1: Dejstva na konstrukcije - Deo 2: Saobraćajna opterećenja na mostovima. 2012.

[10] SRPS EN 1991-2/NA. Evrokod 1: Dejstva na konstrukcije - Deo 2: Saobraćajna opterećenja na mostovima - Nacionalni prilog. 2019.

[11] Freystein, H. Interaktion Gleis/Brücke - Stand der Technik und Beispiele. Stahlbau. 2010. 79: 3. p. 220-231.

[12] MIDAS IT, MIDAS Civil, Available at: https://www.midasuser.com/en/product/civil (accessed May 2026).