VI International Symposium
NEW HORIZONS 2017
of transport and communications
17 - 18 November 2017
www.novihorizonti.rs.ba

TRACK/BRIDGE INTERACTION – THE ASPECT OF BRIDGE STRUCTURE*

Nikola Mirković, Zdenka Popović, Luka Lazarević, Milica Vilotijević
University of Belgrade, Faculty of Civil Engineering, Bulevar kralja Aleksandra 73, 11000 Belgrade, Serbia, nmirkovic@grf.bg.ac.rs, zdenka@grf.bg.ac.rs, llazarevic@grf.bg.ac.rs, mvilotijevic@grf.bg.ac.rs

***Abstract**: The paper presents basic principles of bridge structure behaviour from the aspect of track-bridge interaction in the case of temperature gradient, breaking and acceleration of railway vehicles. The paper analyses influence of different bridge structures to the bridge expansion length. In addition, influence of bridge superstructure, as well as bridge support stiffness was analysed. In the conclusion, there were presented basic observations of conducted analyses that could be applied for the calculation of different railway bridge structures. The aim of this paper is providing the basis for improvement of the existing technical regulations in the field of railway infrastructure, as well as its harmonisation with EU regulations.*

***Key words:** interaction, railway, railway bridge, expansion length, railway substructure.*

1. INTRODUCTION

Bridges shall be designed to support vertical loads in accordance with the load models, defined in (CEN, 2010): Load Model 71 and Load Model SW. The mentioned load models shall be multiplied by the factor alpha (α) as defined also in (CEN, 2010). The minimal values of factor α for the design of new bridges are prescribed in (EUROPEAN COMMISSION, 2014).

Dynamic analysis is required for bridges designed for max. speeds over 200 km/h. In the design of bridge structure following should be taken into account (CEN, 2010; EUROPEAN COMMISSION, 2014):

- centrifugal force in the case of curved track over the whole or part of the bridge length,
- nosing force (frictional lateral force),
- acceleration and breaking forces (longitudinal forces).

In addition, influence of the vehicles (vertical loads, longitudinal acceleration/breaking forces, lateral nosing and centrifugal forces), and temperature changes in bridge deck significantly affect the choice of railway bridge system. Any movement of the bridge deck induces a movement of the CWR (continuous welded rail) track and an additional rail stresses. Track/bridge interaction requires a mutual harmonisation of track superstructure, bridge structure and transition structures for the bridge.

The most important parameters of the bridge structure (support stiffness, expansion and span length, as well as bending stiffness and height of the bridge deck), which influence track/bridge interaction, were considered in this paper. In addition, the longitudinal CWR track

* ***Original scientific paper***

resistance (longitudinal slipping restraint and/or longitudinal displacement resistance of rail) was considered.

The goal of this paper is harmonisation of tehnical requirements for railway bridge design and maintenance on interoperable lines in order to achieve the free flow of passengers and freight with the use of rail transport.

2. PARAMETERS OF THE BRIDGE STRUCTURE

Interaction of vehicle/track/bridge plays a key role in design and maintenance of railway bridges.

Forces induced by the vehicles (vertical load and longitudinal forces during acceleration/breaking of the vehicles), as well as temperature changes and bridge displacement affect track superstructure, especially the rails. Control of the vehicle/track/bridge interaction requires appropriate calculations that correspond to the structure and length of the bridge.

Parameters of the track/bridge interaction, the principles of the calculation, as well as the overview of open points will be presented in the next part of the paper.

2.1. Bridge expansion lengths

Bridge expansion lengths depend on the static system and the bridge span. According to (UIC, 2001), maximum bridge expansion lengths with one or more tracks, either ballasted or slab track, with continuously welded rails are determined:

- 60 m for steel bridges,
- 90 m for concrete and composite bridge structures.

Recommended maximum expansion length of the steel rail bridges is greater than the expansion lengths of the concrete and composite bridge structures because the steel bridges have a greater response to the temperature change in the bridge deck (Table 1).

Table 1. Maximum expansion lengths of bridges in Serbia according to (Službeni glasnik RS, 2016)

Track with continuous welded rails		
	Expansion length of bridge [m]	Necessary measures
Ballasted track	Steel and composite bridges: ≤ 40 m	-
	Concrete bridges: ≤ 60 m	-
	Steel and composite bridges: > 40 m	Calculation of track / bridge interaction
	Concrete bridges: > 60 m	Calculation of track / bridge interaction
Slab track	≤ 40 m for all types of bridges	-
	> 40 m for all types of bridges	Calculation of track / bridge interaction

Table 1 gives the values of bridge expansion lengths according to (Službeni glasnik RS, 2016). The ratio of expansion lengths recommended by (DIN, 2009; UIC, 2001) and the ''*Regulations for Serbian railway bridges*'' are:

- for concrete bridges 90 m /60 m = 1.5,
- for steel bridges 60 m /40 m = 1.5.

2.2. Stiffness of the bridge substructure

Due to the traffic loads and temperature changes, the structure of the bridge deck bends, which leads to additional stresses in the track with CWR (Figure 1).

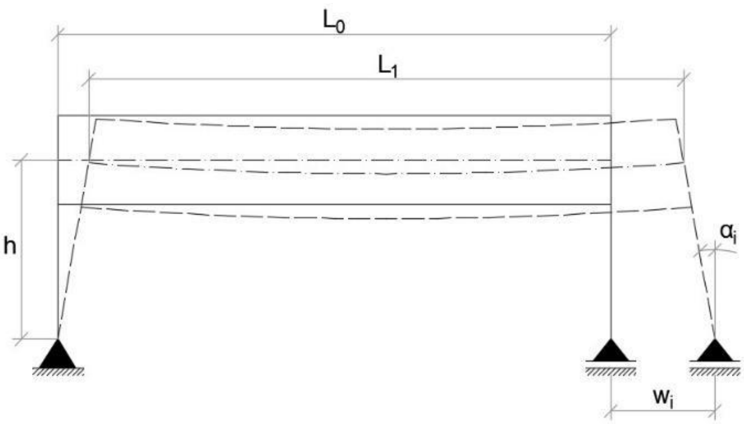

Figure 1. Bending and longitudinal displacement of the bridge structure

Furthermore, additional stresses in the rail due to temperature changes in the bridge deck depend on the stiffness of the supports. Figure 2 shows the additional stresses in CWR in the case of a simply supported beam, taking into account the stiffness of the fixed support.

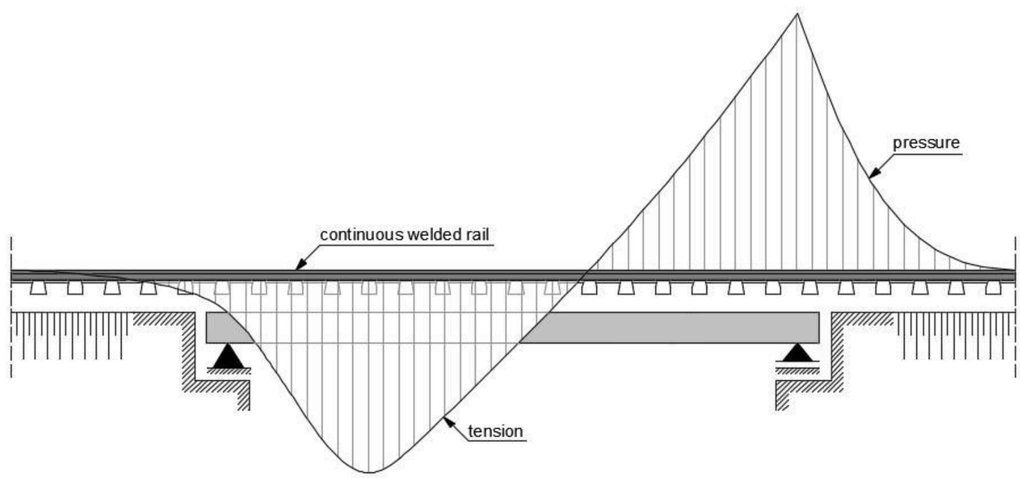

Figure 2. Diagram of additional stresses in the rail due to temperature change in the bridge deck in summer conditions

The share of the load in the fixed bearing or in the track depends to a maximum extent on the stiffness of the bridge substructure (see Figure 2). The total displacement of the support (Figure 3) depends on the stiffness of the bridge substructure, which consists of: (δ_p) bending of the support, (δ_Φ) rotation of the foundation, and (δ_h) displacement of the foundation. The longitudinal stiffness of the support can be determined as the quotient of the longitudinal reaction F_1 and total stiffness.

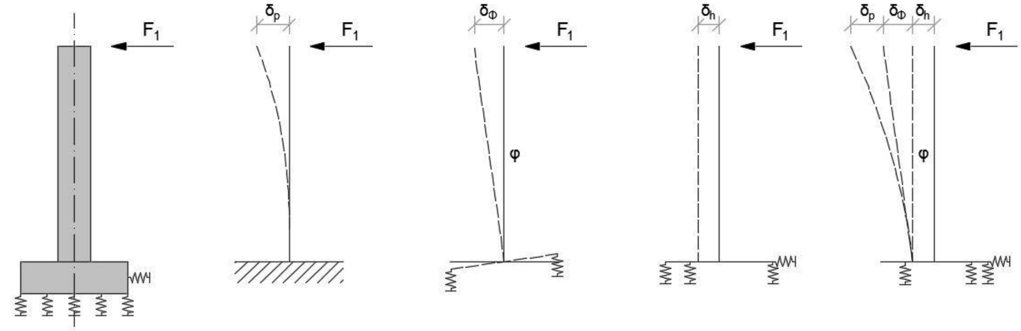

Figure 3. Displacement of the bridge substructure

2.3. Bending stiffness and heigth of the bridge deck

Additional stress in rails may occur due to:

- longitudinal forces,
- the vertical load causing the displacement of the bridge deck ends due to the bending (Figure 4).

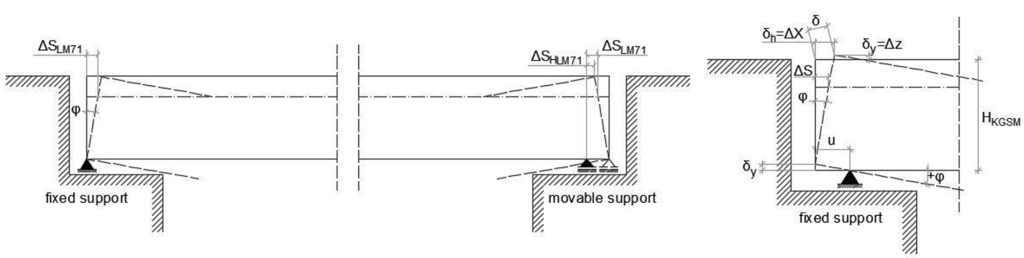

Figure 4. Longitudinal and vertical displacement at the ends of the bridge deck (Freystein, 2010)

In the case of movable support, the resulting longitudinal displacement at the end (Figure 4 on the left) is determined as the difference of displacement due to the bending (ΔS_{LM71}) and longitudinal displacement of the supports (ΔS_{HLM71}).

Vertical displacement due to the rotation of the ends of bridge deck under the traffic influence depends on the length of the overhang "u" behind the axis of the support (Figure 4 right, Table 2). This is of particular relevance in the case of large height of the structure of the bridge deck, e.g. bridges with box cross sections. In such cases, the overhang "u" should be designed to be as least as possible.

Table 2. Limit values of displacement of the end of the bridge deck due to vertical load from traffic (Freystein, 2010)

Limit value of deformation on overhang due to traffic load		
End span length	Design speed V	Limit value δ
≤ 3 m	V ≤ 160 km/h	δ= 5 mm
≤ 3 m	160 km/h < V < 230 km/h	δ= 4 mm
≤ 3 m	V > 230 km/h	δ= 3 mm
≥ 25 m	for all V	δ= 9 mm
3 m < L < 25 m	Intermediate values are obtained by linear interpolation	

3. THE EFFECTS OF BREAKING AND ACCELERATION OF THE VEHICLE ON THE BRIDGE

The breaking and acceleration forces from the vehicle act on the track structure and the bridge deck. They have a short-term effect as opposed to the forces due to temperature changes.

The breaking and acceleration forces from the vehicle are limited with the maximum available friction in the wheel/rail contact (steel on steel). Behind the breaking vehicle, tensioning stress occurs. On the other hand, the pressure stress in the rail is generated in front of the vehicle (Figure 5).

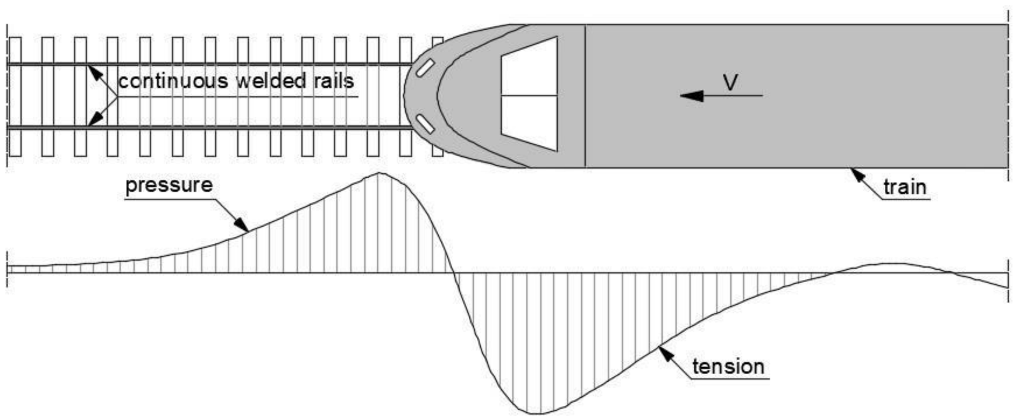

Figure 5. The diagram of the stress in the rail due to the braking of the train

According to (DIN, 2011; UIC, 2001), following maximum acceleration and breaking forces for railway vehicles have been determined:

- Acceleration force of vehicle Q_{Iak} for load models 71, SW/0, SW/2 and HSLM:
  $Q_{Iak} = 33$ kN/m * L_{Iak} [m] ≤ 1000 kN, (1)
- Breaking force Q_{Ibk} for load models 71, SW/0 and HSLM:
  $Q_{Ibk} = 20$ kN/m * L_{Ibk} [m] ≤ 6000 kN, (2a)
  and for load model SW/2:
  $Q_{Ibk} = 35$ kN/m * L_{Ibk} [m] (2b)

The usual values of the impact lengths and the breaking and acceleration forces are shown in Table 3.

Table 3. Parameters of breaking and acceleration load

Type of Track	Acceleration loads Magnitude of Load	Loaded length	Breaking loads Magnitude of Load	Loaded length
High-speed railway	33 kN/m/track	33 m	20 kN/m/track	400 m
Normal railway	24 kN/m/track	33 m	12 kN/m/track	300 m

4. EXPANSION JOINTS IN THE TRACK ON BRIDGE

If the maximum expansion length of 60 m or 90 m cannot be maintained due to the topography or other constraints, it is necessary to reduce the additional strain in the rails in another way. One way implies installing the expansion joints in the track above the movable support at the end of the bridge in order to reduce the strain in the rails due to the displacement of the bridge deck (Figure 6).

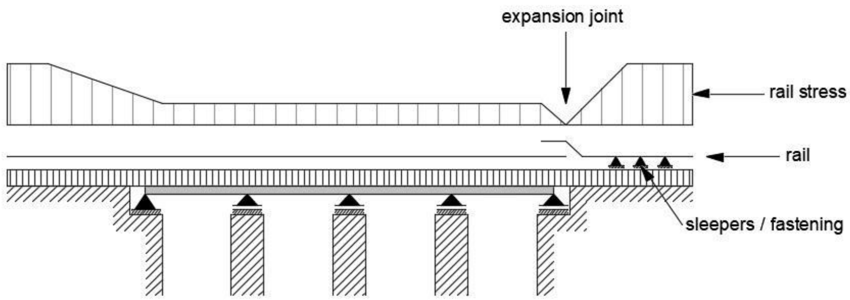

Figure 6. Strain in the rail at the movable end of the bridge with rail expansion joint

However, rail expansion joints should be omitted due to their:

- high price of production and installation,
- high maintenance costs, and
- adverse influence to the driving comfort.

The total longitudinal displacements of the railway bridge deck are shown in Figure 7.

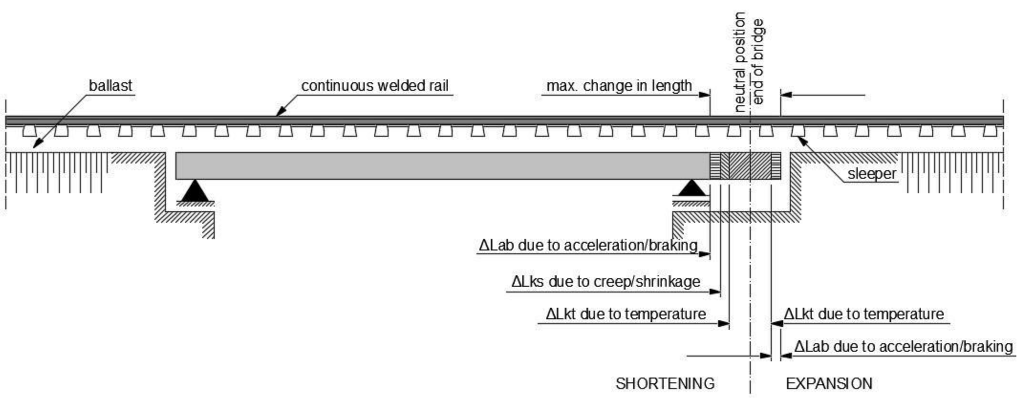

Figure 7. Parameters for designing the required capacity of the expansion joints

5. DISCUSSION AND CONCLUSION

Railways of Serbia are a part of the European rail network and their development should be in compliance with the European transport policy. Two European traffic corridors pass through Serbia: The Danube corridor VII and the road – railway corridor X. Sustainable transport policy in Serbia define directions of development in order to upgrade railway traffic (Popović et al., 2017). The main goal for the railway corridor X through Serbia is reconstruction of the existing railway lines, which implies construction of the second track on the single track sections and electrificaton in order to enable railway corridor for train speeds up to 200 km/h. One of the prerequisities to achieve this goal is harmonisation of Serbian technical regulations in the field of railway infrastructure (Popović et al., 2013).

Considerations in this paper should provide the basis for harmonisation of technical regulations in the field of railway bridges in order to comply with interoperability requirements.

Managing the problems of track/bridge interaction means that the bridge fully fulfills its function and carries the load from the track structure without damaging it. This applies both to the slab track, as well as to the ballasted track on the bridge.

For the research of track/bridge interaction, the following should be known:

- static system of the bridge,
- behaviour of the bearings,
- behaviour of supports (bearings and piers),
- total stiffness of supports (bearings and piers),
- behaviour of the bridge deck during bending.

Cases that could lead to the track/bridge deck interaction are:

- thermal displacement of the bridge deck in case of continuously welded rails,
- thermal displacement of the bridge deck and rails when rail expansion joint is installed in the track,
- horizontal forces due to acceleration/breaking of vehicle,
- rotation of the bridge ends due to the bridge deck bending under vertical load,
- displacement of the bridge deck due to creep and shrinkage of concrete, and
- longitudinal displacement of bridge supports due to the temperature difference in piers.

It should be noted that in the case of track with continuously welded rails, temperature change in the rails does not lead to displacement of the track, therefore there is no interaction with the bridge.

In addition, forces due to vehicle acceleration/breaking should be combined with appropriate vertical loads on the bridge. In the case of a bridge with multiple tracks, the acceleration forces on the one track must be combined with breaking forces on the other track. Only two tracks should be taken into account.

The impact of the vertical load must be examined in terms of rotation and displacement of the bridge deck ends. Impacts for each support at the ends of bridge deck should be examined.

The total stress in continuously welded rails is determined according to calculation of the track stability. The total stress includes the additional stresses in the rails due to the interaction.

Displacement of the bridge deck and track must remain within the certain limits, in order to prevent deconsolidation of the ballast and large longitudinal stresses in the rails.

Rail expansion joints on the bridge should be omitted if it is possible. However, rail expansion joint should be placed at the free end of the bridge deck if the total additional rail strain and/or displacements exceed the prescribed values.

In the case of change of the track conditions (e.g. maintenance works, breaking of continuously welded rails by installing fishplate joints), rail traffic conditions on the bridge must be adjusted (e.g. not to use breakes).

ACKNOWLEDGEMENT

This work was supported by the Ministry of Education and Science of the Republic of Serbia through the research project No. 36012: "Research of technical-technological, staff and organization capacity of Serbian Railway, from the viewpoint of current and future European Union requirements".

6. REFERENCES

CEN/TC 250: EN 1991-2:2003/AC, (2010)

DIN: Fachbericht 101, Einwirkungen auf Brücken, 2. Auflage (2009)

DIN 1055-7:2002-11 Einwirkungen auf Tragwerke - Teil 7: Temperatureinwirkungen. First published: January (2011)

European commission: regulation (EU) No 1299/2014 on the technical specifications for interoperability relating to the 'infrastructure' subsystem of the rail system in the European Union, *Official Journal of the European Union, L 356/1*, (2014).

Freystein H. (2010): Interaktion Gleis/Brücke – Stand der Technik und Beispiele, *Ernst & Sohn Verlag für Architektur und technische Wissenschaften GmbH & Co. KG, Berlin Stahlbau 79, Heft 3, 220-231, DOI: 10.1002/stab.201001299*

Track/bridge Interaction –Recommendations for calculations, *International union of railways (UIC), UIC Code 774-3*, Paris, (2001)

Popović, Z., Lazarević, L., Vukićević, M., Vilotijević, M., Mirković, N. (2017). The modal shift to sustainable railway transport in Serbia, *MATEC Web of Conferences, Vol. 106, p. 05001, EDP Sciences*

Popović, Z., Lazarević, L., Ižvolt, L. (2013). Potential of the railway infrastructure in Serbia, *Railway transport and logistics 3*, 9-22

Pravilnik o tehničkim uslovima i održavanju gornjeg stroja železničkih pruga, *"Službeni glasnik RS", broj 39*, (2016)