Nikola B. Mirković

Teaching Assistant
University of Belgrade
Faculty of Civil Engineering

Zdenka J. Popović

Full Professor
University of Belgrade
Faculty of Civil Engineering

Andrey P. Pustovgar

Associate Professor
Moscow State University
of Civil Engineering
Russia

Luka M. Lazarević

Assistant Professor
University of Belgrade
Faculty of Civil Engineering

Andrey V. Zhuravlev

PhD Researcher
Moscow State University
of Civil Engineering
Russia

Management of Stresses in the Rails on Railway Bridges

This paper analyses the stresses in continuous welded rails on bridges including the aspect of fatigue of rail steel. Furthermore, it examines the possibility to avoid rail expansion joints, while simultaneously exploiting the permissible stress capacity of the rail profile 60E1. Accordingly, general application of permissible values of pressure and tensilestresses prescribed in the current European standards was critically analysed. Paper includes specific application aspects of the prescribed stress values for railway bridges in Serbia. General algorithm for reducing the stresses due to the vehicle/track/bridge interaction, which is presented in this paper, was developed by the authors.This algorithm includes all essential parameters of the bridge structure and railway superstructure, as well as the influence of climate conditions and railway route design.

Keywords: railway, continuous welded rail, vehicle/track/bridge interaction, fatigue design, rail stressreduction.

1. INTRODUCTION

Sustainable rail traffic has to meet user requirements and maintain competitiveness with other modes of transport. Accordingly, the increase in speed and axle load on the modern railways is evident.Simultaneously, adapting the track to the topographic characteristics and the problems of routing through the urban environment are getting more complex and challenging. Application of shallow radius of horizontal curves and low railway grades for mixed traffic lines contribute to a large number and large length of railway engineering structures (including bridges, viaducts, overpasses etc.). According to current experience, engineering structures could comprise up to 70% (or more) of the length of railway line.

Railway bridges should provide the continuity of the track in order to ensure the same traffic safety and ride comfort along the entire length of railway line. Authors particularly investigated the possibilities to avoid rail expansion joints, in order to provide traffic safety and ride comfort on the railway bridges. This approach contributes to reduction of maintenance costs, as well as adverse environmental impact (noise and vibration).

Considering the dangerous consequences of derail–ment on the bridge (which could be expressed in human lives, injuries, environmental and material damage), importance of research in the area of bridge design and maintenance is obvious. This research includes the analy–sis of the vehicle/track/bridge interaction. The main assu–mption is multidisciplinary approach during design, construction and maintenance of railway bridges (Figure 1). Further considerations are primarily focused on the parameters of the track and bridge structure (blue and orange colour in Figure 1).
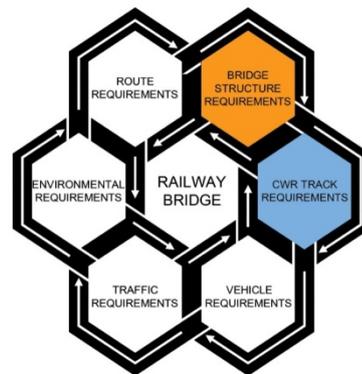
Figure 1. Relevant engineering requirements for solving vehicle/track/bridge interaction

Considerations in the paper refer to the track with continuous welded rail (CWR - Continuous Welded Rail) 60E1 in the ballasted track on the bridge.
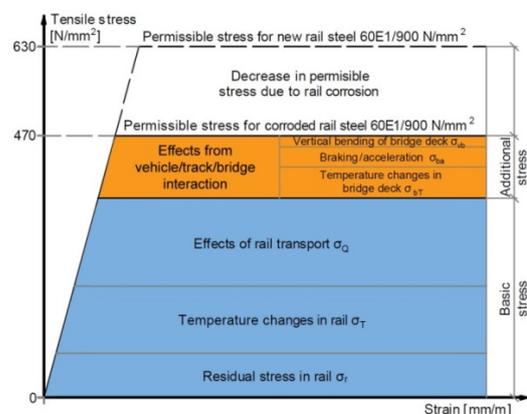
Figure 2. Tensile stress – strain diagram in CWR on the bridge (rail steel 60E1/900 N/mm^2)

Vehicle/track/bridge interaction leads to the occur–rence of additional stresses in rails on the bridge.Figure 2 shows additional tensile stresses in CWR, including

stresses due to temperature changes σ_{bT} and bending of the bridge deck σ_{vb}, as well as braking and acceleration of railway vehicles σ_{ba}.

Similarly, Figure 3 shows additional pressure stresses in CWR including stresses due to temperature changes in the bridge deck. Pressure stress 290 N/mm^2 leading to track buckling is defined according to the results obtained in the previous researches [1, 2].
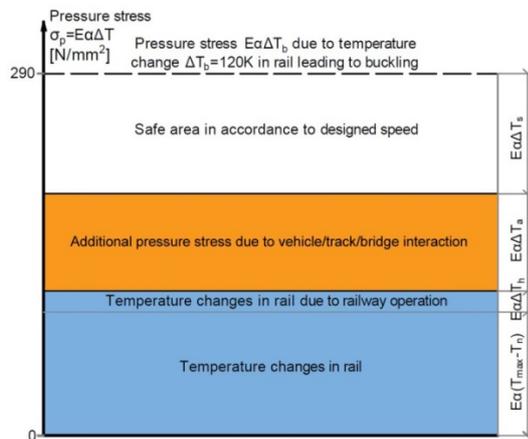
Figure 3. Pressure stress in CWR on the bridge (rail steel 60E1/900 N/mm^2)

Paper includes critical analysis of tensile and pressure stress values in CWR prescribed by European standards for railway bridges. Furthermore, it presents a general algo–rithm for reducing the additional stresses in CWR due to the vehicle/track/bridge interaction. This algorithm, deve–loped by the authors,could be applied by railway infra–structure designers and infrastructure managers through–out the entire lifetime of the track and bridge.

In addition, this paper presents climate conditions in Serbia, which should be considered in the design of railway bridges in order to ensure safety of railway traffic. We investigated the influence of tensile and pressure stress values in rail prescribed in [3-11] considering the specific Serbian climate conditions and presented the results.

2. EUROPEAN REGULATORY FRAMEWORK

Technical regulations for railway bridges should be based on the results of vehicle/track/bridge interaction analysis. Considering the complex requirements of rail transport, as well as long service life of railway bridges, the need for critical analysis of current technical regulations and its adaptation to in-service condition is obvious.

The problem of determining the stresses in CWR on the bridge and transfer of the longitudinal forces to the bridge bearings was considered by International Union of Railways (UIC). In 1995, the first edition of UIC Leaflet 774-3 provided recommendations for calculation of track/bridge interaction, which presented the basisfor development of relevant European standards. In 1999, European Rail Research Institute (ERRI) formed an expert commission to modify UIC Leaflet 774-3. The upgraded second edition of UIC Leaflet 774-3 was published in August 2001 [11].

In 2003, European Committee for Standardization (CEN) published EN 1991-2 [3], which is based on previously mentioned research by ERRI [11]. European

standard [3] defines loads (models and representative values) associated with road traffic, pedestrian actions and railway traffic, which include dynamic effects and centrifugal, braking/acceleration actions and actions for accidental situations. Section 6 of the standard [3] includes railway traffic actions and other actions that occur on railway bridges. Furthermore, Annex A2 in [4] provides calculation procedure, which contains the necessary factors for combination/frequent/quasi-per–manent values of variable actions.In addition, CEN has published standards for design of concrete, steel, and composite steel/concrete bridges [5-7].

UIC Code 776-1 [8] and UIC Code 776-2 [9] provide recommendations for vehicle/track/bridge inter–action calculation. UIC leaflet [8] defines loads to be considered in railway bridge design, and UIC leaflet [9] defines design requirements for railway bridges.

In addition, the railway bridges have to meet the interoperability requirements for the European railway system in accordance with Technical Specifications for Interoperability (TSI). TSI represents obligation for European railway system and basis for national rules and regulations. Resistance of new and existing railway bridges and embankments to traffic load is defined as basic parameter of the infrastructure subsystem and should meet the essential requirements defined in [11].

Railway bridges have to be designed to support vertical loads according to the load models defined in EN 1991-2. The mentioned load models should be multiplied by the factor alpha α[3]. The minimal values of factor α for the design of new bridges are prescribed in [10]. Dynamic analysis is required for railway bridges desig–ned for maximum speeds over 200 km/h [3, 10].

According to [3, 10], calculation of railway bridge structure includes centrifugal force (for curved track over the whole or part of the bridge length), nosing force (frictional lateral force), and acceleration/braking forces (occasional longitudinal forces).

Previously considered technical regulations for rail–way bridges [3-11] present European regulatory frame–work for the development of harmonised national regulations, which have to incorporate national specifics (climate, traffic, maintenance strategy etc.) in order to ensure the interoperability of the railway system.

3. ANALYSIS OF TENSILE STRESSES INCWR USING SMITH DIAGRAM

European standard EN 1991-2 [3] prescribes permi–ssible values of additional stressesin CWR on the bridge in accordance with [11,12], which refer to the technical properties of railway superstructure affecting lateral and longitudinal track resistance:
- 60E1 rail profile according to [13],
- steel grade at least R260 according to [13](tensile strength of at least 900 N/mm^2),
- rail fastening systems for ballasted track in accor–dance to European standard EN 13481series,
- maximum spacing of heavy concrete sleepers (e.g. B70 sleeper type) up to 65 cm in ballasted track or equivalent ballasted track structure,
- minimum 30 cm thickness of consolidated ballast under the sleeper contact surface (at rail placement).

Furthermore, permissible values refer to the technical properties of railway alignment on the bridge (including adjacent abutments) straight track, and/or minimum track radius 1500 m.

When the previous criteria are not satisfied, specific analysis and calculation should be carried out or additional measures defined.

An open point still remains -whether the prescribed values of the additional stresses [3,11, 12] in CWR could be applied regardless of: (a) specific climate conditions (extremely low/high temperatures in CWR and bridge), (b) traffic requirements (high braking/acceleration frequency), and (c) rail manufacturing technology (wide range of residual stresses up to 250MPa according to [13])?

The decrease in permissible stress in the corroded rail compared to the new rail 60E1/900 (tensile strength 900 N/m^2) is presented in Smith diagram (Figure 4). Permissible additional tensile stresses in rail foot can be determined from Smith diagram for corroded rail steel. Corrosion of the rail foot occurs due to the chemical substances in air and/or water, or due to the electrolytic actions induced by stray current. Corrosion could result in a rail break due to the profile reduction and this is the reason to analyse permissible values for additional stresses in corroded rails.

Figure 4 shows permissible tensile bending strength in rail foot centre according to Smith diagram for new and corroded rails with a tensile strength 900 N/m^2.If the estimated value of the stress due to bridge deck bending is σ_{vb}=20 N/mm^2, the free stress σ_f^* is112-20=92 N/mm^2 according to [3,11,12,14].If the value of stress due to bridge deck bending σ_{vb} is determined by calculation, the free tensile stress in the rail foot σ_f amounts 112 N/mm^2 according to the research presented in dissertation by Freystein [14].

In both above cases, it is assumed that the residual stress in rail foot is 80 N/mm^2 and the tensile stress due to the temperature change in CWR is 120 N/mm^2.

In Figure 4, the total basic tensile stress is 358 N/mm^2, representing the sum of the following: σ_r=80 N/mm^2, σ_T=120 N/mm^2,and σ_Q=158N/mm^2. The additional free tensile stress amounts 470-358=112 N/mm^2, whereby the available zone of dynamic stresses includes only the effects of bridge deck bending σ_{vb}=20 N/mm^2. Accordingly, influences due to braking and temperature changes in the bridge deck is 112-20=92 N/mm^2 (Figure 4).

Stress due to railway traffic load σ_Q presents the part of basic tensile stress and significantly influences fatigue of rail steel. Value σ_Q=158 N/mm^2 in Figure 4 corresponds to following technical properties of railway superstructure: 60E1 rail profile, B70W concrete sleepers with elastic rail fastening system, sleeper spacing up to 65 cm, and good track foundation (track modulus C=0.1 N/mm^3). Calculation was performed for light high-speed trains, as well as for heavy slow trains, usingreference combination, which implied speed up to 200 km/h [15]. Furthermore, calculation considered unequal wheel load distribution in curves, as well as dynamic influences.

In Figure 4, value σ_T=120 N/mm^2 corresponds to temperature change during winter conditions:

$$\Delta T_{RT} = \frac{\sigma_T}{E \cdot \alpha} = \frac{120}{2.415} \approx 50K \quad (1)$$

$$\Delta T_{RT} = T_n - T_{min} \quad (2)$$

where:
ΔT_{RT} - difference between minimum rail temperature T_{min} and neutral temperature T_n,
E=210 GPa- Young`smodulus for rail steel,
α=1,15·10^{-5} 1/K - coefficient of thermal expansion.

Figure 4.Smith diagram for new and corroded rail 60E1/900 (left) and fatigue stress diagrams (right)

Residual stress in Figure 4 is presented as a part of basic tensile stress in rail. In the manufacturing process, generated in rails during hot rolling are uneven cooling, as well as roller straightening and levelling. For Vignole rails [13], the mass is concentrated in the rail head and the middle of the rail foot. In these areas, the cooling process takes a longer period than in the rest of rail profile (Figure 5). Furthermore, Figure 6 presents distribution of residual stresses in rail head, web and foot for new and used rails [16].

Figure 5. The uneven cooling of rail profile and bending of the rails in cooling bed
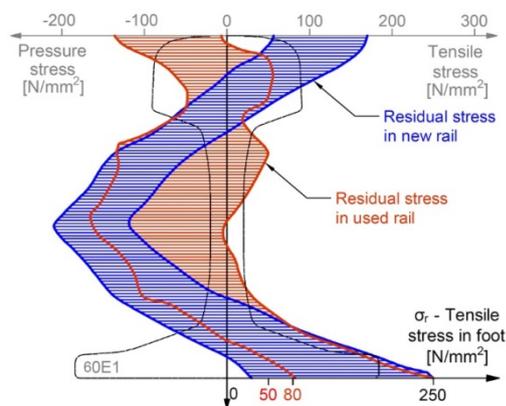
Figure 6. Distribution of residual stresses in rail

4. ANALYSIS OF PRESSURE STRESSES IN CWR

The permissible value of additional pressure in CWR due to vehicle/track/bridge interaction is $\sigma_P=72$ N/mm^2 for ballasted track [3,11,12].

Track buckling on the bridge is a representative criterion for defining the permissible additional pressure in CWR. The critical temperature increases in the rail during summer conditions, which might lead to track buckling. This critical temperature is 122 K according to [1,2,17], or approximately 120 K according to [18]. The critical temperature corresponds to the following technical properties of railway superstructure: 60E1 rail profile, B70W concrete sleepers with elastic rail fastening system, sleeper spacing up to 65 cm, and good track foundation (track modulus C=0.1 N/mm^3). Furthermore, the following should be met: (a) track

alignment deviation of 4.5 mm for high-speed lines, (b) dynamic resistance to the lateral displacement of track w_Q=10 kN/m.

The reserve of representative temperature change ΔT_R could be obtained using the following equations:

$$\Delta T_R = \frac{\sigma_P}{E \cdot \alpha} = \frac{72}{2.415} \approx 30\,K \qquad (3)$$

$$\Delta T_R = 120\,K - \left(\Delta T_{RP} + \Delta T_S + \Delta T_{RE}\right) \qquad (4)$$

where:
ΔT_{RP} - difference between maximum rail temperature T_{max} and neutral temperature T_n,
ΔT_S - safety temperature change according to Table 1,
ΔT_{RE} - rail elongation under the influence of traffic load corresponding to the temperature change of 3 K.

Table 1. Safety temperature change [16]

V [km/h]	≤80	100	120	140	160	230
ΔT_S [K]	10	20	25	30	40	50
$E\alpha\Delta T_S$ [N/mm^2]	24.15	48.30	60.38	72.45	96.60	120.75

The difference of 30 K could be calculated and expressed through the additional pressure stress in the rail of 72 N/mm^2, which ensures track stability against buckling.

5. DISCUSSION OF PERMISSIBLE VALUES FOR AXIAL STRESSES IN CWR ON THE BRIDGE

In accordance with design criteria for rails on the bridge and on the adjacent abutments [3], the permissible addi–tional rail stresses due to the combined response of the bridge structure and ballasted track to variable actions should be limited to 72 N/mm^2 for the pressure stress and 92 N/mm^2 for the tensile stress.

Moreover, the alternative requirements should be specified in the National Annex. Following discussion concerns specific requirements for vehicle/track/bridge interaction in Serbia.

Prescribed values for permissible tensile stresses in the rail foot [3,11,12], which are presented in Smith diagram (Figure 4) imply properties of railway super–structure and technical properties of railway alignment defined in Chapter 3, as well as the following:
- mixed traffic line for speed up to 200 km/h,
- temperature change in rails up to $\Delta T_{RT}<50$ K (σ_T=120 N/mm^2),
- tensile stresses up to σ_r=80 N/mm^2.

It should be mentioned that value σ_r=80 N/mm^2 corresponds to rail profile 49E1 (previous profile S49) according to German superstructure design regulation from 1992. On the other hand, results in dissertation [19] shown that rail profile 60E1 has significantly larger residual stresses due to larger mass. Furthermore, EN 13674-1 defines the maximum longitudinal residual stress in the rail foot up to 250 N/mm^2 for all steel grades, which has to be determined using destructive cutting method [13]. Residual stress could be determined using non-destructive methods, such as X-ray diffraction,

ultrasonic velocity, Barkhausen noise analysis etc. [18], but only for relative comparing to cutting method [13].

Rail manufacturing process (especially cooling) significantly influences residual stress distribution in rail profile (Figure 6). The rail market already provides rails which were manufactured using "optimal cooling, straightening and levelling technology" with residual stress σ_r^*=50 N/mm^2(Figure 4).

Free tensile stress value σ_f=112 N/mm^2 (Figure4) is derived based onthe assumption that residual stress equals 80 N/mm^2, which does not necessarily correspond to rail profile 60E1. In any case, calculation of CWR should include real value of residual stress in the foot of corroded and used rail profile 60E1 (Figure 6), considering current rail market.

Furthermore, local climate conditions and neutral temperature value significantly influence ΔT_{RT}. Hence, ΔT_{RT}=50 K cannot be prescribed in general.For example, Serbian Infrastructure Manager prescribed T_n=22,5^{o}C.On the other hand, ΔT_{RT} could have different values depending on climate region and considering global climate changes in Serbia.Figure 7 presents temperatures in rails for two monitoring places (SremskiKarlovci and Priboj) for last three years, which correspond to significant climate change in Serbia.
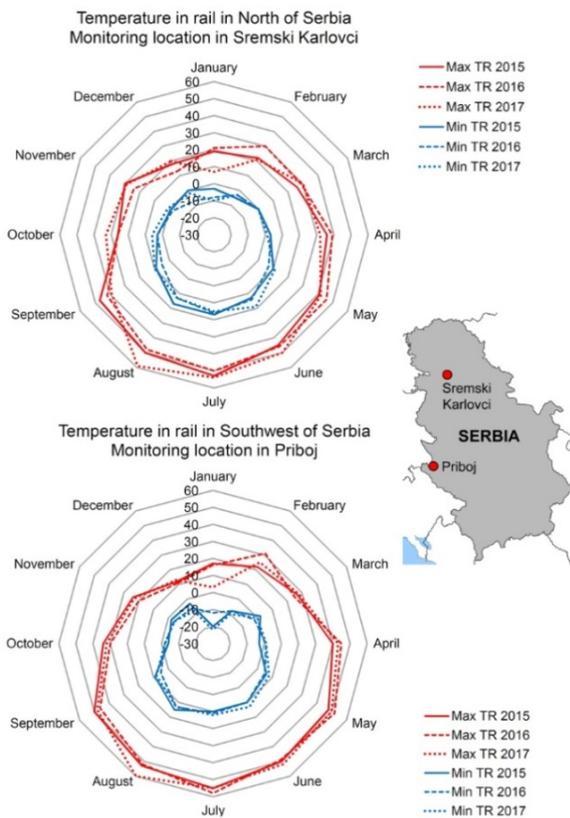
Figure 7.Results of temperature monitoring in Sremski Karlovci (up) and Priboj (down) in Serbia

Figure 4 shows that σ_{vb}=20 N/mm^2 is an estimated value which refers to available zone of dynamic stresses. Furthermore, bridge deck bending stress σ_{vb} and stress due to the traffic load σ_Q have to belong to available zone of dynamic stresses. Exact value for σ_{vb} could be calculated and it could be larger, equal or less than 20 N/mm^2. Considering the starting assumptions in this Chapter, if σ_{vb}>20 N/mm^2, it is necessary to reduce

permissible stress in rail thus enabling both σ_Q and σ_{vb} stresses to pertain in available zone of dynamic stresses.

In Figure 4, stresses due to braking/acceleration σ_{ba} does not belong to available zone of dynamic stresses in Smith diagram. This means that braking/acceleration occurs exceptionally. In case when railway station is located on the bridge, or right before/after the bridge, σ_{ba}, σ_Q and σ_{vb} have to belong to available zone of dynamic stresses in Smith diagram. This case demands calculation of appropriate permissible additional stress σ_f≠92 N/mm^2.

According to equation (4), permissible value for temperature difference between maximum rail temperature T_{max} and neutral temperature T_n in CWR is:

$$\Delta T_{RP} = 120 - (30 + 50 + 3) = 37 \, \text{K} \qquad (5)$$

If it is considered that neutral temperature is 22,5°C, then maximum allowed temperature in CWR equals:

$$T_{max} = 37°C + 22.5°C = 59.5°C \qquad (6)$$

which corresponds to permissible pressure stress of 72 N/mm^2.

Calculated T_{max} coincides with values that are used on majority of European railway networks. For example, maximum temperature in rail measured in Germany is58°C [17]. Considering that air temperatures measured in August were above 42°C during last several years in Serbia, it is necessary to reduce value of permissible pressure stress in rails$\sigma_p$according to climate region.

6. PROPOSED ALGORITHM FOR MANAGEMENT OF THE STRESSES IN CWR DUE TO THEVEHICLE/TRACK/BRIDGE INTERACTION

This paper proposes general algorithm for management of the stresses in CWR on the bridge respecting the multidisciplinary approach (Figure 1). The main goal of managing the stresses in CWR is to avoid rail expansion joints on the bridge. The algorithm is developed by the authors of this paper and presented in Figure 9.

After defining the rail route, mutual adjustment of bridge and track structure contributes to the reduction in maintenance costs of railway infrastructure and vehic–les, decrease in the negative environmental impact (noi–se and vibration), as well as increase of ride comfort due to the omitting of the rail expansion joints[20, 21].

The developed algorithm for management of the stresses in CWR includes specific requirements dis–cussed in Chapter 5 (residual stresses in rails according to manufacturing technology and temperature changes according to climate region). Furthermore, stress management has to include specific influence of the bridge position on the railway route, especially when railway station or signal is located on the bridge, or right before/after the bridge (frequent braking/acceleration).In such circumstances, influence of the braking/acceleration has to be considered as dynamic load. This could lead to decrease in permissible tensile stress in the rail foot (Figure 4).

If applying the procedure from proposed algorithm (steps A-G in Figure 9) does not provide acceptable technical solution for vehicle/track/bridge interaction, ballastless track structure on the bridge could be

considered (permissible pressure/tensile stress amounts 92 N/mm² - step H).

In the case when it is not possible to apply ballastless track structure, step I provides option to change railway route and bridge position in order to achieve shorter expansion length and, if necessary, larger curvature (1/R) of the bridge.

The last step of algorithm(stepJ in Figure 9) offers technical solution for exceeding the permissible pressure stress in CWR above the last movable bridge support – installation of the rail expansion joints(Figure 8).This solution could be applied regardless of the circumstances, but it is the worst solution regarding cost-effectiveness and ride comfort. Design of expansion capacity has to include temperature changes (according to climate region), as well as influence of braking/acceleration.

Analysing the vehicle/track/bridge interaction and using the developed algorithm, possible competitive technical solutions for track and bridge structure could be created. Optimal technical solution should be determined using multi-criteria analysis techniques.

Figure 9 presents appropriate comments for each algorithm step (A-K). In addition, step H includes option to ensure track stability using ballastless track instead of ballasted track. However, detailed considerations in this paper are limited to ballasted track. Due to the specific requirements, results of the analyses of ballastless track on reconstructed and new bridges require separate presentation.
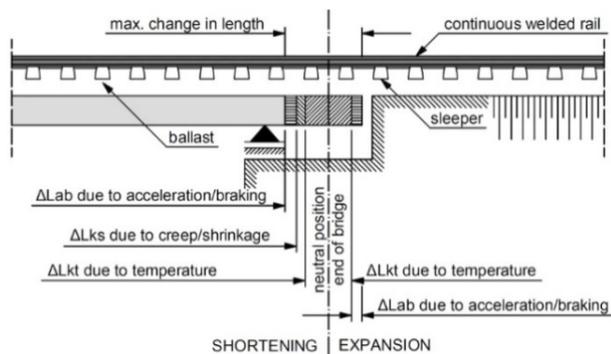
Figure 8.Referent influences for design of expansion capacity of rail expansion joint on the bridge

7. CONCLUSION

According to the structure of basic and additional stresses (Figures 2 and 3), this paper points out that the com–ponents of total stress in CWR depend strongly on: (1) type of railway line (design speed, axle load, pas–senger, freight or mixed traffic, number of tracks), (2) bridge position on the railway route (curvature 1/R, railway sta–tion located on the bridge, or right before/after the bridge, signal position), (3) climate zone (relevant temperature changes in bridge deck and CWR), and (4) rail manu–facturing technology (residual stresses according to [13]).

For ballasted track on the bridge, the prescribed permissible values of tensile (92 N/mm²) and pressure stress (72 N/mm²) in the rail in accordance with EN 1990:2002 [4] were critically analysed in Chapters 3-5. According to the Smith diagram for corroded rail

60E1/900 and fatigue stress diagrams (Figure 4) it was pointed out that values of permissible stresses [4] in CWR cannot be used in case of frequent vehicle braking/ ace–leration on the bridge (due to the station and/or signal). In such circumstances, the influence of vehicle braking/ ace–leration has to be considered as fatigue stress (Figure 4), hence defining appropriate lower value of permissible rail stress. Furthermore, the paper points out that the analysis of additional stresses in CWR has to incorporate the influence of modern braking systems on track stability (Table 1).

Chapter 5 discusses permissible values for axial stresses in CWR on the bridge. Additionally, it presents the influence of climate regions in Serbia (Figure 7) on permissible stress values due to the temperature changes in bridge and rails.

The permissible additional rail stresses due to the combined response of the bridge structure and track (design criteria for track on the bridge and on adjacent abutments) have to strongly comply with real requirements of railway route, traffic regime, rail manufacturing technology, and climate change/region. Otherwise, uncritical application of design criteria defined in European standard EN 1990:2002 [4] could jeopardise railway traffic safety.

Based on the previous, this paper proposed the general algorithm, developed by the authors, which generates possible technical solutions for the track and bridge structure with reduced stresses due to the interaction of the following:
- vehicle: passenger and/or freight traffic (maxi–mum speed, maximum axle load), and traffic regime (braking/acceleration),
- track: ballasted (CWR, rail fastening system, concrete sleepers, ballast), and ballastless (CWR, rail fastening system, concrete/asphalt slab, concrete sleepers if necessary, hydraulic stabi–lized base layer, and
- bridge: alignment (straight or curve), and struc–ture parameters (static arrangement - system, expansion length, layout and stiffness of supp–orts, deck stiffness).

The main contribution of the proposed algorithm is the development of technical solutions of the railway bridges as an integral part of the railway route design by respecting current rail manufacturing technology, cli–mate conditions, traffic regime and avoiding of the rail expansion joints.Mutual adjustment of railway align–ment, bridge and track structure increases:(a) ride com–fort due to the omittingof the rail expansion joints whenever it is technically possible, and (b) traffic safety through satisfying local climate, topographic and geo–technical requirements[22], as well as considering the rolling stockparameters (i.e.different braking systems [23, 24] installed in rail vehicles).

8. ACKNOWLEDGEMENT

Figure 9.General algorithm for reducing the stresses in rails due to vehicle/track/bridge interaction

The flowchart consists of the following nodes from START to END:

- START
- (A) Input data: suggested bridge position, bridge and track structure
- (K) Output data: defined bridge position, bridge and track structure → END
- (B) Exceeded axial stresses in rails and relative displacements — NO → (output)
- YES ↓
- (C) Modification of bridge static arrangement
- (B) Exceeded axial stresses in rails and relative displacements — NO
- YES ↓
- (D) Modification of bridge expansion length
- (B) Exceeded axial stresses in rails and relative displacements — NO
- YES ↓
- (E) Modification of bridge support stiffness
- (B) Exceeded axial stresses in rails and relative displacements — NO
- YES ↓
- (F) Modification of bridge deck stiffness
- (B) Exceeded axial stresses in rails and relative displacements — NO
- YES ↓
- (G) Modification of rail fastening system
- (B) Exceeded axial stresses in rails and relative displacements — NO
- YES ↓
- (H) Modification of railway superstructure
- (B) Exceeded axial stresses in rails and relative displacements — NO
- YES ↓
- (I) Modification of railway bridge position on railway route — YES (loop back to start)
- NO ↓
- (J) Installation of rail expansion joint

(A) Comment: Input data about bridge position on the railway route includes suggested position of the bridge, horizontal (bridge in straight or in curve radius R_{min}=1500 m) and vertical alignment. Input data about bridge superstructure includes suggested static arrangement with support layout and span composition, as well as expansion length, stiffness of bridge deck and supports (Eurocode 1-4 [3-7]). Input data about track includes technical properties of railway superstructure with ballasted track and CWR (without rail expansion joints) in accordance to Chapter 3. According to INF TSI, the rail fastening system is relevant to the requirements for track resistance under vertical loads. The rail fastening system should comply with laboratory test requirements prescribed in EN 13146-1: longitudinal force required to cause the rail to begin to slip (i.e. move in an inelastic way) over a single rail fastening assembly shall be at least 7 kN, but for speeds higher than 250 km/h should be at least 9 kN.

(B) Comment: Permissible design values of stresses in CWR (ballasted track) are 72 N/mm^2 for pressure stress and 92 N/mm^2 for tensile stress. Permissible design values for displacements include the maximum permissible displacement between rail and deck or embankment under braking/acceleration forces (up to 4 mm) and the maximum absolute horizontal displacement of the deck due to braking/acceleration forces (up to ±5 mm if the rails run across one or both ends of the bridge/embankment transition) [11]
Note: National technical regulations have to be applied if they prescribe stricter requirements in relation to European standards .

(C) Comment: The static arrangement of the bridge is defined by the number of decks, the number of supports per deck, positions of fixed and movable supports, the span lengths, and the expansion length(s). The most usual static arrangement is combination of simply-supported deck(s) and/or continuous deck(s).

(D) Comment: The expansion length is the distance between the fixed thermal point and the opposite end of the deck. The position of this point depends on the position and type of supports. In case of deck succession the total expansion length is the sum of the expansion lengths of the two nearest decks. According to UIC Code 774-3 [11] maximum bridge expansion length with one or more tracks, either ballasted or slab track, with CWR is 60 m for steel bridge structure and 90 m for concrete and composite bridge structures. Recommended maximum expansion length of the steel bridges is greater than the expansion length of the concrete and composite bridge structures due to the greater response of steel bridges to the temperature change in the bridge deck.

(E) Comment: The total support stiffness includes stiffness of each support. The longitudinal stiffness of the support could be determined as the quotient of the longitudinal reaction and the total displacement. The total displacement of the support depends on the stiffness of bridge substructure, which consists of: (δ_p) bending of the support, (δ_φ) rotation of the foundation, (δ_h) foundation displacement, (δ_a) relative displacement between the upper and lower parts of the bearing [11].

(F) Comment: Vertical traffic loads on the bridge generate large track/bridge interaction forces as a result of deck bending, which causes longitudinal displacement of the upper edge of the deck end. The interaction depends primarily on the flexibility of the deck and on the position of its neutral axis, but it is also influenced by the stiffness of the fixed elastic support and by the height of the deck. Horizontal displacement of the deck due to the traffic loads remains constant when considered along the neutral axis, but varies when measured at the upper part of the slab supporting the track.

(G) Comment: Rail fastening system with reduced longitudinal resistance [20] should reduce the pressure in CWR in the zone of movable support at the bridge end (for example: Pandrol ZLR - **Z**ero **L**ongitudinal **R**estraint, Vossloh fastening system with SKL B12 or SKL MK clips etc.), in order to avoid rail expansion joints.

(H) Comment: Application of slab track (ballastless superstructure) instead of the ballasted track in order to avoid rail expansion joints and provide track buckling safety (permissible rail pressure stress is 92 N/mm^2).

(I) Comment: Changing the bridge position on the railway route aims to reduction of curvature (1/R) and/or reduction of the expansion length of the displaced bridge.

(J) Comment: If changing the railway route is not possible, rail expansion joints should be installed as the only possible technical solution. The maximum permissible absolute horizontal displacement of the deck is 30 mm in the case of ballasted track with rail expansion joints.

(K) Comment: This step generates possible competitive technical solutions for track and bridge structure. Output data provide bridge position on railway route, bridge structure (static arrangement, expansion length, support stiffness, deck stiffness), as well as track structure (CWR, technical requirements for rail fastening system, and, if necessary, rail expansion joints).

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УПРАВЉАЊЕ НАПОНИМА У ШИНАМА НА ЖЕЛЕЗНИЧКИМ МОСТОВИМА

Н. Мирковић, З. Поповић, А. Пустовгар, Л. Лазаревић, А. Журавлев

Овај рад анализира напоне у континуално завареним шинама на мостовима, укључујући аспект замора шинског челика. Поред тога, испитује се могућност изостављања шинских дилатационих справа, уз истовремено искоришћење капацитета дозвољених напона за профил шине 60Е1. У складу са тим, критички је анализирана општа примена дозвољених вредности напона притиска и затезања које су прописане у важећим европским стандардима. Рад укључује аспекте посебне примене прописаних вредности напона за железничке мостове у Србији. У раду је представљен општи алгоритам за смањење напона услед интеракције возило/колосек/мост, који је развијен од стране аутора. Овај алгоритам укључује све битне параметре конструкције моста и горњег строја железничке пруге, као и утицај климатских услова и пројекта трасе пруге.