ŽELEZNIČKI MOSTOVI NA INTEROPERABILNIM PRUGAMA - ASPEKT INTERAKCIJE KOLOSEK/MOST

RAILWAY BRIDGES ON INTEROPERABLE LINES - ASPECT OF TRACK/BRIDGE INTERACTION

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PREGLEDNI RAD
REVIEW PAPER
UDK: 624.21.046:625.14
doi:10.5937/GRMK1802019M

1 UVOD

Stabilnost mostova (novih i postojećih) i nasipa pod saobraćajnim opterećenjem pripada osnovnim parametrima podsistema za infrastrukturu i treba da ispunjava osnovne zahteve definisane u „Tehničkim specifikacijama interoperabilnosti koje se odnose na podsistem za infrastrukturu” (INF TSI) [6].

Mostovi se projektuju tako da mogu da prihvate vertikalno opterećenje u skladu sa šemama opterećenja, definisanim u [2]: šema opterećenja 71 i šema opterećenja SW. Pomenute šeme opterećenja treba pomnožiti faktorom alfa (α) kako je definisano u [2]. Minimalna vrednost faktora α za projektovanje novih mostova propisana je u [6].

Dinamička analiza zahteva se za mostove za maksimalne brzine preko 200 km/h [2, 6]. Pri projektovanju mostova treba uzeti u obzir sledeće uticaje [2, 6]:

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1 INTRODUCTION

Resistance of bridges (new and existing) and earthworks to traffic load belong to basic parameters of the infrastructure subsystem and should meet the essential requirements defined in ''*The technical specifications for interoperability relating to the infrastructure subsystem*'' (INF TSI) [6].

Bridges shall be designed to support vertical loads in accordance with the load models, defined in [2]: Load Model 71 and Load Model SW. The mentioned load models shall be multiplied by the factor alpha (α) as defined in [2]. The minimal values of factor α for the design of new bridges are prescribed in [6].

Dynamic analysis is required for bridges designed for max. speeds over 200 km/h [2, 6]. In the design of bridge structure the following should be taken into account [2, 6]:

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– centrifugalnu silu u slučaju koloseka koji je delom ili celom dužinom mosta u krivini,
– fiktivnu bočnu silu,
– sile ubrzavanja i kočenja (podužne sile).

Dodatno, pored uticaja od vozila (vertikalno opterećenje, podužne sile ubrzavanja/kočenja, fiktivne bočne i centrifugalne sile), promena temperature u konstrukciji gornjeg stroja mosta značajno utiče na izbor statičkog sistema železničkog mosta. Svako pomeranje konstrukcije gornjeg stroja mosta izaziva pomeranje koloseka sa kontinualno zavarenim šinama i dodatne napone u šini. Interakcija kolosek/most zahteva međusobno usaglašavanje konstrukcije gornjeg stroja pruge, mosta i prelazne konstrukcije sa nasipa na most.

U ovom radu su razmatrani najvažniji parametri konstrukcije mosta (krutost oslonaca, dilataciona dužina i dužina raspona, kao i krutost na savijanje i visina konstrukcije gornjeg stroja mosta), koji utiču na interakciju kolosek/most. Pored toga, razmatran je otpor podužnom pomeranju koloseka sa kontinualno zavarenim šinama (otpor podužnom pomeranju šine u odnosu na prag i/ili otpor podužnom pomeranju praga kroz zastor).

Cilj rada je harmonizacija tehničkih zahteva za projektovanje i održavanje železničkih mostova na interoperabilnim prugama kako bi se ostvario slobodan protok putnika i tereta uz korišćenje železničkog saobraćaja.

– centrifugal force in the case of curved track over the whole or part of the bridge length,
– nosing force (frictional lateral force), and
– 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 resistance (longitudinal slipping restraint and/or longitudinal displacement resistance of rail) was considered.

The goal of this paper is harmonisation of technical 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 OKVIR ZA TEHNIČKU REGULATIVU - TRENUTNO STANJE

Osnovni dokument koji definiše zahteve za železničke mostove jeste INF TSI [6]. U UIC objavama [8-11] date su preporuke za razmatranje interakcije vozilo/kolosek/most. One predstavljaju osnovu za razvoj EN standarda. Pomenute UIC objave definisale su modele statičkog opterećenja koje treba uzeti u razmatranje pri projektovanju železničkih mostova i dale su preporuke za proračune zasnovane na interakciji između vozila, koloseka i konstrukcije mosta.

Merodavni evrokodovi za mostove prikazani su u tabeli 1. Harmonizacija ovih evrokodova je deklarisani cilj Evropske komisije sa ciljem slobodnog toka železničkog saobraćaja. Posebno značajan za železničke mostove je EN 1991-2 [2] koji definiše opterećenja na mostovima.

2 THE FRAMEWORK FOR TECHNICAL REGULATIONS - STATE OF THE ART

The basic document that defines the requirements for the railway bridges is INF TSI [6]. UIC leaflets [8-11] provide recommendations for consideration of the vehicle/track/bridge interaction. These leaflets were the base for the development of EN standards, and they defined the static loading models to be taken into consideration for the railway bridge design and provided recommendations for calculations based on interaction between vehicle, track and bridge structure.

The relevant Eurocodes for railway bridges are presented in Table 1. The harmonisation of these Eurocodes is declared aim of the European Commission for the purpose of free traffic flow. Particularly important for railway bridges is the EN 1991-2 [2] which defines loads on bridges.

Tabela 1. Trenutno stanje referentnih srpskih standarda SRPS EN za mostove
Table 1. State of the art of relevant Serbian standards SRPS EN for bridges

Srpska oznaka (Serbian designation)	Naslov na srpskom (Title in Serbian)	Naslov na engleskom (Title in English)
SRPS EN 1990:2012	Evrokod - Osnove projektovanja konstrukcija	Eurocode - Basis of structural design
SRPS EN 1990/NA:2012	Evrokod - Osnove projektovanja konstrukcija - Nacionalni prilog	Eurocode - Basis of structural design - National Annex
SRPS EN 1991-1-1:2012	Evrokod 1 - Dejstva na konstrukcije - Deo 1-1: Opšta dejstva - Zapreminske težine, sopstvena težina, korisna opterećenja za zgrade	Eurocode 1: Actions on structures - Part 1-1: General actions - Densities, self-weight, imposed loads for buildings
SRPS EN 1991-1-1/NA:2015	Evrokod 1 - Dejstva na konstrukcije - Deo 1-1: Opšta dejstva - Zapreminske težine, sopstvena težina, korisna opterećenja za zgrade - Nacionalni prilog	Eurocode 1: Actions on structures - Part 1-1: General actions - Densities, self-weight, imposed loads for buildings - National Annex

SRPS EN 1991-1-2:2012	Evrokod 1 - Dejstva na konstrukcije - Deo 1-2: Opšta dejstva - Dejstvo na konstrukcije izložene požaru	Eurocode 1: Actions on structures - Part 1-2: General actions - Actions on structures exposed to fire
SRPS EN 1991-1-3:2012	Evrokod 1 - Dejstva na konstrukcije - Deo 1 - 3: Opšta dejstva - Opterećenja snegom	Eurocode 1 - Actions on structures - Part 1-3: General actions - Snow loads
SRPS EN 1991-1-4:2012	Evrokod 1 - Dejstva na konstrukcije - Deo 1 - 4: Opšta dejstva - Dejstva vetra	Eurocode 1: Actions on structures - Part 1-4: General actions - Wind actions
SRPS EN 1991-1-5:2012	Evrokod 1 - Dejstva na konstrukcije - Deo 1 - 5: Opšta dejstva - Toplotna dejstva	Eurocode 1: Actions on structures - Part 1-5: General actions - Thermal actions
SRPS EN 1991-1-5/NA:2017	Evrokod 1 - Dejstva na konstrukcije - Deo 1 - 5: Opšta dejstva - Toplotna dejstva - Nacionalni prilog	Eurocode 1: Actions on structures - Part 1-5: General actions - Thermal actions - National Annex
SRPS EN 1991-1-6:2012	Evrokod 1 - Dejstva na konstrukcije - Deo 1 - 6: Opšta dejstva - Dejstva tokom izvođenja	Eurocode 1 - Actions on structures Part 1-6: General actions - Actions during execution
naSRPS EN 1991-1-6/NA:2015	Evrokod 1 - Dejstva na konstrukcije - Deo 1 - 6: Opšta dejstva - Dejstva tokom izvođenja - Nacionalni prilog	Eurocode 1 - Actions on structures - Part 1-6: General actions - Actions during execution - National Annex
SRPS EN 1991-2:2012	Evrokod 1 - Dejstva na konstrukcije - Deo 2: Saobraćajno opterećenje na mostovima	Eurocode 1: Actions on structures - Part 2: Traffic loads on bridges
SRPS EN 1992-2:2014	Evrokod 2 - Projektovanje betonskih konstrukcija - Betonski mostovi - Pravila projektovanja i konstruisanja	Eurocode 2 - Design of concrete structures - Concrete bridges - Design and detailing rules
SRPS EN 1992-2/NA:2015	Evrokod 2 - Projektovanje betonskih konstrukcija - Betonski mostovi - Pravila projektovanja i konstruisanja - Nacionalni prilog	Eurocode 2 - Design of concrete structures - Concrete bridges - Design and detailing rules - National Annex
SRPS EN 1993-2:2012	Evrokod 3 - Projektovanje čeličnih konstrukcija - Deo 2: Čelični mostovi	Eurocode 3 - Design of steel structures - Part 2: Steel Bridges
SRPS EN 1993-2/NA:2013	Evrokod 3 - Projektovanje čeličnih konstrukcija - Deo 2: Čelični mostovi - Nacionalni prilog	Eurocode 3: Design of steel structures - Part 2: Steel bridges - National Annex
SRPS EN 1994-2:2012	Evrokod 4 - Projektovanje spregnutih konstrukcija od čelika i betona - Deo 2: Opšta pravila i pravila za mostove	Eurocode 4 - Design of composite steel and concrete structures - Part 2: General rules and rules for bridges
SRPS EN 1994-2/NA:2016	Evrokod 4 - Projektovanje spregnutih konstrukcija od čelika i betona - Deo 2: Opšta pravila i pravila za mostove - Nacionalni prilog	Eurocode 4 - Design of composite steel and concrete structures - Part 2: General rules and rules for bridges - National Annex
SRPS EN 1997-1:2017	Evrokod 7 - Geotehničko projektovanje - Deo 1: Opšta pravila	Eurocode 7: Geotechnical design - Part 1: General rules
SRPS EN 1997-2:2014	Evrokod 7 - Geotehničko projektovanje - Deo 2: Istraživanje tla i ispitivanje	Eurocode 7 - Geotechnical design - Part 2: Ground investigation and testing
SRPS EN 1998-1:2015	Evrokod 8 - Projektovanje seizmički otpornih konstrukcija - Deo 1: Opšta pravila, seizmička dejstva i pravila za zgrade	Eurocode 8: Design of structures for earthquake resistance - Part 1: General rules, seismic actions and rules for buildings
SRPS EN 1998-2:2012	Evrokod 8 - Projektovanje seizmički otpornih konstrukcija - Deo 2: Mostovi	Eurocode 8: Design of structures for earthquake resistance - Part 2: Bridges

3 PARAMETRI KONSTRUKCIJE MOSTA

Interakcija vozila, koloseka i mosta igra značajnu ulogu u projektovanju i održavanju železničkih mostova.

Zbog sila od vozila (vertikalno opterećenje, podužne sile pri pokretanju i kočenju vozila), kao i temperaturnih promena i dilatacija mosta, pojaviće se uticaji u konstrukciji gornjeg stroja železničke pruge, a naročito u šinama. Upravljanje interakcijom vozilo/kolosek/most zahteva odgovarajuće postupke proračuna koji odgovaraju konstrukciji i dužini mosta.

U daljem tekstu će se predstaviti parametri

3 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 interakcije kolosek/most, principi proračuna, kao i pregled otvorenih pitanja.

3.1 Dužine dilatiranja mosta

Dužine dilatiranja mosta zavise od statičkog sistema i raspona mosta. Prema UIC Code 774-3 [9] utvrđene su maksimalne dilatacione dužine mostova sa jednim kolosekom i više koloseka u zastoru od tucanika ili na čvrstoj podlozi sa kontinualno zavarenim šinama:

– 60 m za čelične mostove,
– 90 m za betonske i spregnute mostove.

Propisana maksimalna dilataciona dužina čeličnih železničkih mostova veća je od dilatacionih dužina betonskih i spregnutih konstrukcija mostova zato što čelični mostovi imaju izraženiji odziv na promenu temperature u konstrukciji gornjeg stroja mosta.

U tabeli 2 prikazane su merodavne temperature za čelične, spregnute i betonske konstrukcije mostova na nemačkim železnicama prema [4].

principles of the calculation, as well as the overview of open points will be presented in the following part of the paper.

3.1 Bridge expansion lengths

Bridge expansion lengths depend on the static system and the bridge span. According to UIC Code 774-3 [9], 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 greater response to the temperature change in the bridge deck.

Table 2 shows the representative temperatures for the steel, composite and concrete bridge structures on German railways according to [4].

Tabela 2. Temperaturna promena u zavisnosti od vrste konstrukcije mosta
Table 2. Temperature change depending on the type of bridge structure

Bridge type (Tip mosta)	*Minimum temperature* (Minimalna temperatura) $T_{e,min}$	*Maximum temperature* (Maksimalna temperatura) $T_{e,max}$	*Temperature change* (Temperaturna promena)		*Temperature amplitude* (Temperaturna amplituda) ΔT
			$\Delta T_{N,neg}$	$\Delta T_{N,poz}$	
	°C				
Steel bridge (Čelični most)	-26	+51	-36	+41	77
Composite bridge (Spregnuti most)	-20	+41	-30	+31	61
Concrete bridge (Betonski most)	-17	+37	-27	+27	54

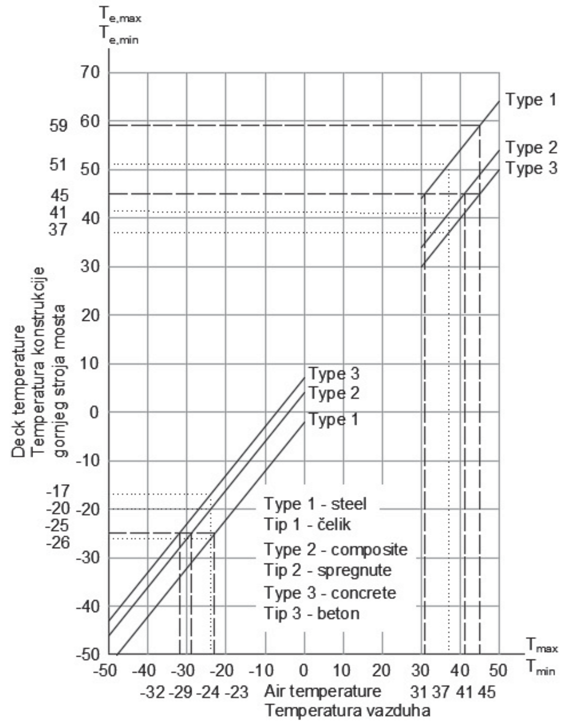
Note: The neutral temperature of the bridge, at which the bearings are installed, is 10°C according to [4]. The value of neutral temperature is determined by the Infrastructure Manager.
(Napomena: Neutralna temperatura mosta, pri kojoj se ugrađuju ležišta, je 10°C prema [4].Vrednost neutralne temperature utvrđuje Upravljač infrastrukture).

Na slici 1 dat je dijagram temperatura u gornjem stroju mosta na osnovu spoljne temperature prema [4]. Temperature predstavljene u tabeli 2 određene su iz dijagrama sa slike 1 unošenjem ekstremnih spoljnih temperatura -24°C i +37°C prema [5]. Pored toga, na dijagramu (slika 1) predstavljene su temperature u gornjem stroju mosta prema [16]. Naime, prema članu 43 pravilnika [16] ekstremne temperature mosta na železnicama Srbije jesu -25 °C i +45°C. Prema [16] neutralna temperatura za most je t_o=t_{sr}=0,5·(45-25)=10°C (isto kao prema [4]). Može se zaključiti da temperature propisane u [16] zadovoljavaju ekstremne spoljne temperature -32°C i +45°C u slučaju betonskih mostova. Prema [17] izmereni temperaturni ekstremi u Srbiji su:

– najviša temperatura od +44,9°C (izmerena je 24.07.2007. godine u Smederevskoj Palanci),
– najniža temperatura od -39,0°C (izmerena je 26.01.2006. godine u Karajukića Bunarima na Pešterskoj visoravni).

Figure 1 shows a temperature diagram in the bridge deck based on air temperature according to [4]. The temperatures presented in Table 2 were determined using the diagram in Figure 1 by considering extreme air temperatures -24°C and +37°C according to [5]. In addition, the diagram in Figure 1 represents the temperatures in the bridge deck as defined in [16]. According to article 43 in [16], extreme bridge temperatures on the Serbian railways are -25°C and +45°C, and neutral temperature for the bridge is t_o = t_{sr} = 0.5(45-25) = 10°C (the same as in [4]). It can be concluded that the temperatures given in [16] meet the extreme air temperatures in Serbia, which equal -32 °C and +45°C in the case of concrete bridges. According to [17] measured extreme temperatures in Serbia are:

– the highest temperature of +44,9 °C (measured on July 24, 2007 in Smederevska Palanka),
– the lowest temperature of -39,0 °C (measured on January 26, 2006 in Karajukić Bunari on Pešterska visoravan).



Slika 1. Temperatura u konstrukciji gornjeg stroja mosta u zavisnosti od temperature vazduha (isprekidanom linijom su predstavljene temperature u Srbiji) [4]

Figure 1. Temperature in the bridge deck depending on the air temperature (dashed line presented the temperature in Serbia) [4]

U tabeli 3 date su vrednosti dilatacionih dužina mostova prema [16]. Odnos dilatacionih dužina koje se preporučuju u [4, 9] i „Pravilniku za železničke mostove u Srbiji" [16] jeste:

- za betonske mostove 90 m/60 m=1,5,
- za čelične mostove 60 m/40 m=1,5.

Table 3 gives the values of bridge expansion lengths according to [16]. The ratio of expansion lengths recommended by [4, 9] and the ''*Regulations for Serbian railway bridges*'' [16] are:

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

Tabela 3. Maksimalne dilatacione dužine na mostovima u Srbiji prema [16]
Table 3. Maximum expansion lengths of bridges in Serbia according to [14]

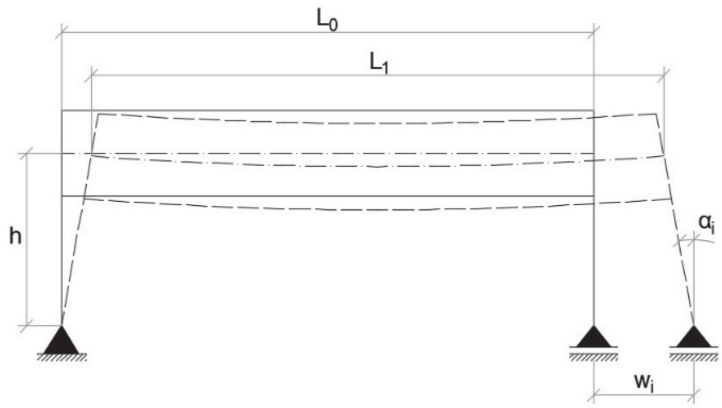
Track with continuous welded rails (Kolosek sa kontinualno zavarenim šinama)		
	Expansion length of bridge [m] (Dilataciona dužina mosta [m])	*Necessary measures* (Potrebne mere)
Ballasted track (Kolosek u zastoru od tucanika)	*Steel and composite bridges*: ≤ 40 m (Čelični i spregnuti mostovi: ≤ 40 m)	-
	Concrete bridges: ≤ 60 m (Betonski mostovi: ≤ 60 m)	
	Steel and composite bridges: > 40 m (Čelični i spregnuti mostovi: > 40 m)	*Calculation of track / bridge interaction* (Proračun interakcije kolosek / most)
	Concrete bridges: > 60 m (Betonski mostovi: > 60 m)	
Slab track (Kolosek na čvrstoj podlozi)	≤ 40 m *for all types of bridges* (≤ 40 m za sve tipove mostova)	-
	> 40 m *for all types of bridges* (> 40 m za sve tipove mostova)	*Calculation of track / bridge interaction* (Proračun interakcije kolosek / most)

3.2 Krutost konstrukcije donjeg stroja mosta

Pod uticajem opterećenja od saobraćaja i temperaturnih promena, savijaju se i pomeraju konstrukcije gornjeg stroja mosta i javljaju dodatni naponi u koloseku sa kontinualno zavarenim šinama (slika 2).

3.2 Stiffness of the bridge substructure

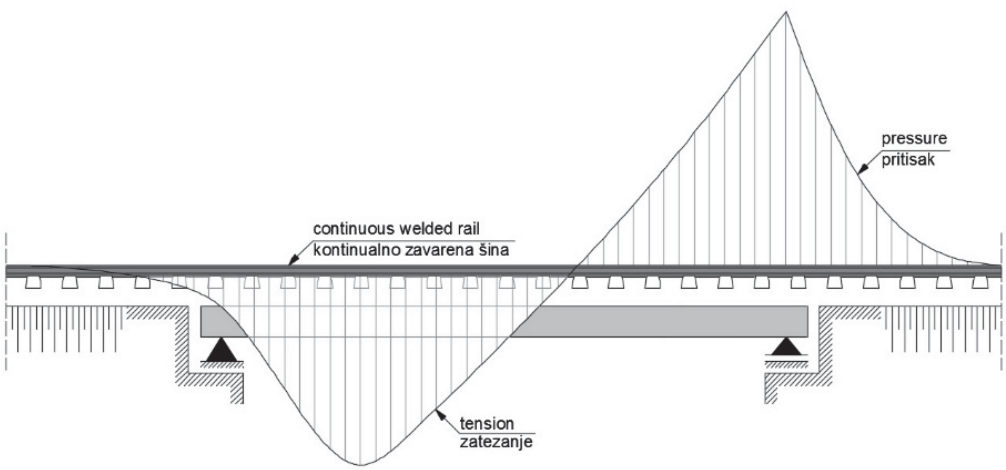
Due to the traffic loads and temperature changes, the structure of the bridge deck bends, which leads to additional stresses in the track with CWR (Figure 2).



Slika 2. Savijanje i podužno pomeranje konstrukcije mosta
Figure 2. Bending and longitudinal displacement of the bridge structure

Dodatni naponi u šinama zbog temperaturnih promena u konstrukciji gornjeg stroja mosta takođe zavise od krutosti oslonaca. Slika 3 prikazuje normalni tok dodatnih napona u kontinualno zavarenim šinama u slučaju proste grede uz uzimanje u obzir krutosti nepokretnog oslonca.

Furthermore, additional stresses in the rail due to temperature changes in the bridge deck depend on the stiffness of the supports. Figure 3 shows the additional stresses in CWR in the case of a simply supported beam, taking into account the stiffness of the fixed support.



Slika 3. Dijagram dodatnih napona u šini usled termičkih pomeranja konstrukcije gornjeg stroja mosta u letnjim uslovima
Figure 3. Diagram of additional stresses in the rail due to temperature change in the bridge deck in summer conditions

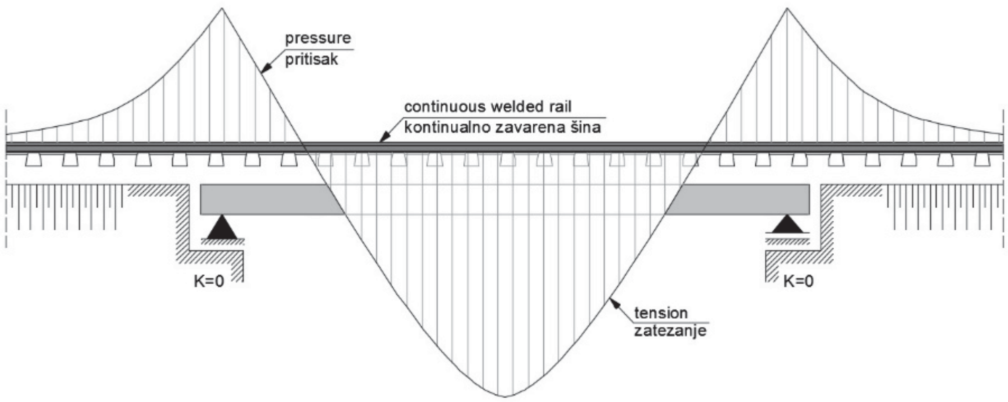
Teorijski posmatrano, ukoliko bi krutost oslonaca iznosila K=0, dijagram dodatnih napona u letnjim uslovima imao bi oblik kao na slici 4.

Udeo opterećenja u nepokretnom ležištu odnosno u koloseku zavisi u najvećoj meri od krutosti konstrukcije donjeg stroja mosta (videti slike 3 i 4). Ukupno pomeranje oslonca (slika 5) zavisi od krutosti konstrukcije donjeg stroja mosta i sastoji se od: (δ_p) savijanja oslonca, (δ_Φ) zaokretanja temelja, i (δ_h) pomeranja

Theoretically, if the stiffness of all bridge supports equal K = 0, the diagram of additional stresses in summer conditions would have the form as in Figure 4.

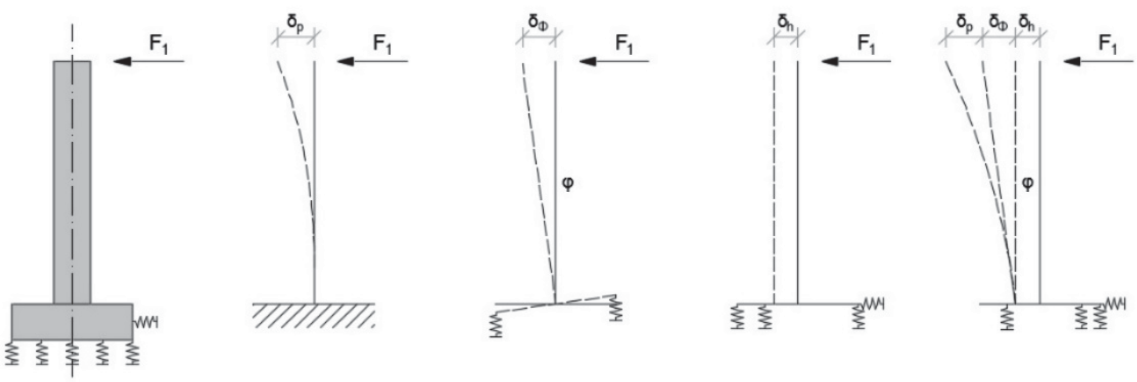
The share of the load in the fixed bearing or in the track depends to a maximum extent on the stiffness of the bridge substructure (see Figure 3 and 4). The total displacement of the support (Figure 5) depends on the stiffness of the bridge substructure, which consists of: (δ_p) bending of the support, (δ_Φ) rotation of the temelja. Podužna krutost oslonca se može odrediti kao količnik podužne reakcije F_1 i ukupne krutosti.

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.



Slika 4. Dijagram dodatnih napona u šini usled termičkih pomeranja konstrukcije gornjeg stroja mosta u letnjim uslovima za krutost oslonaca K=0

Figure 4 Diagram of additional stresses in the rail due to temperature change in the bridge deck in summer conditions for the supports stiffness K = 0



Slika 5. Pomeranja konstrukcije donjeg stroja mosta

Figure 5. Displacement of the bridge substructure

3.3 Krutost na savijanje i visina konstrukcije gornjeg stroja mosta

Dodatna naprezanja šine mogu da nastanu usled:

– sila koje deluju u podužnom pravcu,

– vertikalnog opterećenja koje izaziva pomeranje krajeva usled savijanja konstrukcije gornjeg stroja mosta (slika 6).

Rezultujuće podužno pomeranje na kraju sa pokretnim osloncem (slika 6 levo) određuje se kao razlika pomeranja usled savijanja (ΔS_{LM71}) i podužnog pomeranja oslonaca (ΔS_{HLM71}).

Vertikalno pomeranje zbog zaokretanja krajeva gornjeg stroja mosta usled uticaja od saobraćaja zavisi od dužine prepusta "*u*" iza ose oslonca (slika 6 desno, tabela 4). To je od naročitog značaja u slučaju velikih visina konstrukcije gornjeg stroja mosta, npr. kod sandučastih konstrukcija. U takvim slučajevima, treba da se izabere što manji prepust preko oslonca.

3.3 Bending stiffness and height of the bridge deck

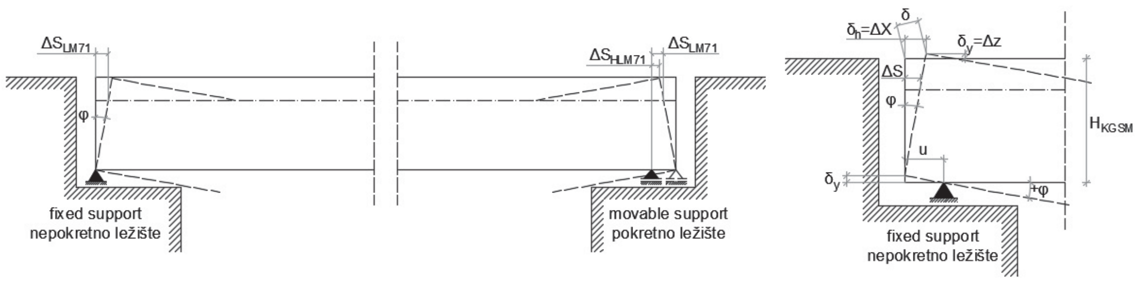
Additional stress in rails may occur due to:

– longitudinal forces,

– the vertical load causing the displacement of the bridge deck ends due to the bending (Figure 6).

In the case of movable support, the resulting longitudinal displacement at the end (Figure 6 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 (Fig. 6 right, Table 4). 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.



Slika 6. Podužna i vertikalna pomeranja na krajevima konstrukcije gornjeg stroja mosta [7]
Figure 6. Longitudinal and vertical displacement at the ends of the bridge deck [7]

Tabela 4. Granične vrednosti pomeranja kraja konstrukcije gornjeg stroja mosta usled vertikalnog opterećanja od saobraćaja [7]
Table 4. Limit values of displacement of the end of the bridge deck due to vertical load from traffic [7]

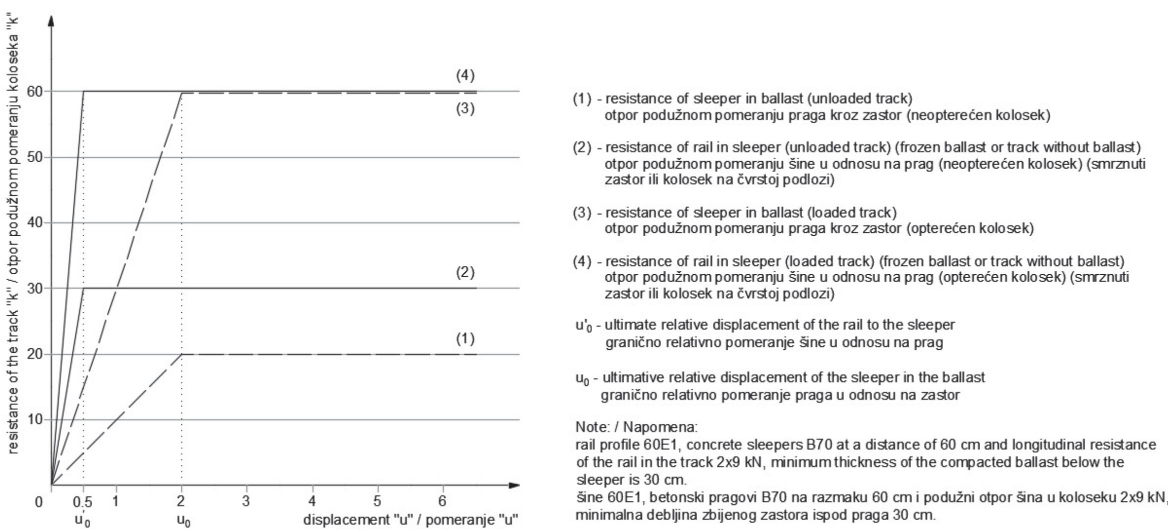
Limit value of deformation on overhang due to traffic load (Granična vrednost deformacije na prepustu usled saobraćajnog opterećenja)		
End span length (Raspon krajnjeg polja)	*Design speed* V (Projektna brzina V)	*Limit value* δ (Granična vrednost δ)
≤ 3 m	V ≤ 160 km/h	δ= 5 mm
	160 km/h < V < 230 km/h	δ= 4 mm
	V > 230 km/h	δ= 3 mm
≥ 25 m	*for all* (za sve) V	δ= 9 mm
3 m < L < 25 m	*Intermediate values are obtained by linear interpolation* (Međuvrednosti se dobijaju linearnom interpolacijom)	

4 OTPOR PODUŽNOM POMERANJU KOLOSEKA SA KONTINUALNO ZAVARENIM ŠINAMA

Ponašanje koloseka u podužnom pravcu razmatra se kao otpor podužnom pomeranju konstrukcije koloseka (u zastoru od tucanika) i otpor klizanju šine po pričvršćenju (merodavan u zimskim uslovima kada je tucanik u zastornoj prizmi smrznut i u slučaju koloseka na čvrstoj podlozi). Tok pomeranja je nelinearan, ali se za praktičnu upotrebu uprošćuje bilinearnom funkcijom (slika 7). Vrednost otpora zavisi od toga da li je kolosek opterećen ili neopterećen.

4 LONGITUDINAL RESISTANCE OF THE TRACK WITH CONTINUOUS WELDED RAIL

Behaviour of the track in the longitudinal direction is considered as a resistance to the longitudinal displacement of the track structure (in the ballasted track) and the resistance to the rail slipping over fastening system (applicable for winter conditions when the ballast is frozen, as well as in the case of slab track). Displacement is non-linear, but for practical use it is simplified to the bilinear function (Figure 7). The resistance value depends on whether the track is loaded or unloaded.



Slika 7. Otpori podužnom pomeranju koloseka/šine
Figure 7. Longitudinal resistance to the displacement of the track/rail

Prema INF TSI (tačka 4.2.6.1 u [6]) sistem šinskog pričvršćenja odgovara zahtevu „Stabilnost koloseka pod vertikalnim opterećenjem". Sistem šinskih pričvršćenja ispituje se u laboratorijskim uslovima prema EN 13146-1 i treba da zadovolji sledeće zahteve: podužna sila pri elastičnom pomeranju šine u sistemu šinskog pričvršćenja mora da bude najmanje 7 kN, a na prugama za brzine veće od 250 km/h mora da bude najmanje 9 kN. Ukoliko je potrebno, dopušteno je smanjenje podužnog otpora sistema šinskog pričvršćenja na mostu radi smanjenja sile pritiska u šini u zoni krajnjeg pokretnog oslonca (uključujući sisteme koji ne pružaju otpor podužnom pomeranju šine, npr. PANDROL® ZRL - **Z**ero **L**ongitudinal **R**estraint).

According to INF TSI (point 4.2.6.1 in [6]), the rail fastening system is relevant to the requirements for "*Track resistance under vertical loads*". The rail fastening system should comply with laboratory test conditions, prescribed in EN 13146-1, with the following requirement: the longitudinal force required to cause the rail to begin slipping (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. If necessary, it is permissible to reduce the longitudinal resistance of the rail fastening system on the bridge in order to reduce the pressure in the rail around moving support at the bridge end (including systems that fail to provide resistance to the longitudinal movement of the rail, e.g. PANDROL® ZRL - **Z**ero **L**ongitudinal **R**estraint).

5 UTICAJI KOČENJA I UBRZAVANJA VOZILA NA MOSTU

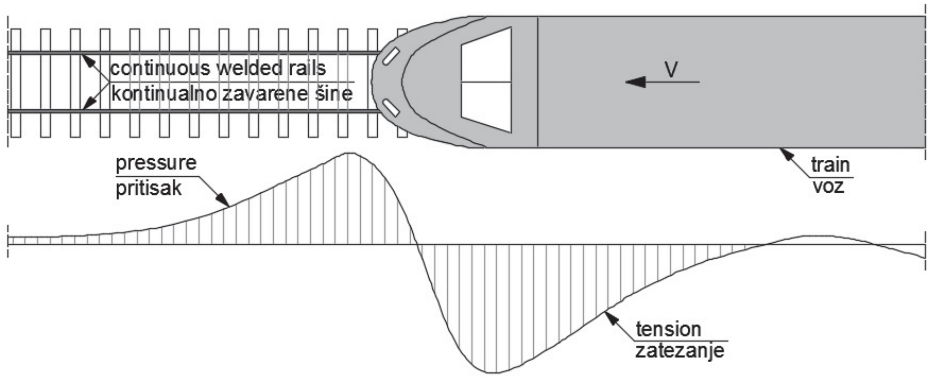
Sile od kočenje i ubrzavanja vozila deluju na konstrukciju koloseka i konstrukciju gornjeg stroja mosta. One imaju kratkotrajni uticaj za razliku od sila usled temperaturnih promena.

Sile od kočenja i ubrzavanja vozila su ograničene na osnovu maksimalnog raspoloživog trenja u dodiru točak/šina (čelik po čeliku). Iza vozila koje koči nastaju naponi zatezanja, dok ispred vozila koje koči nastaju naponi pritiska u šini (slika 8).

5 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 8).



Slika 8. Dijagram napona u šini usled kočenja voza
Figure 8. The diagram of the stress in the rail due to the braking of the train

Na slici 9 prikazano je horizontalno opterećenje koloseka usled kočenja i ubrzavanja vozila. Poređenja radi, prikazan je dijagram sila kočenja za drumski most.

Frikcione kočnice železničkih vozila deluju na osnovu trenja, koje se u većini slučajeva postiže korišćenjem komprimovanog vazduha. Kada mašinovođa aktivira kočnicu, talas vazdušnog pritiska napreduje brzinom 250–280 m/s. Dakle, vozilo koči sa zadrškom – takozvano vreme pripreme kočenja. Odloženo vreme delovanja kočnice, naročito u slučaju dugačkih sastava, dovodi do pojave podužnih dinamičkih sila. Ove sile su posledica nesimultanog kočenja pojedinačnih kola, što dovodi do pojave sila pritiska između njih.

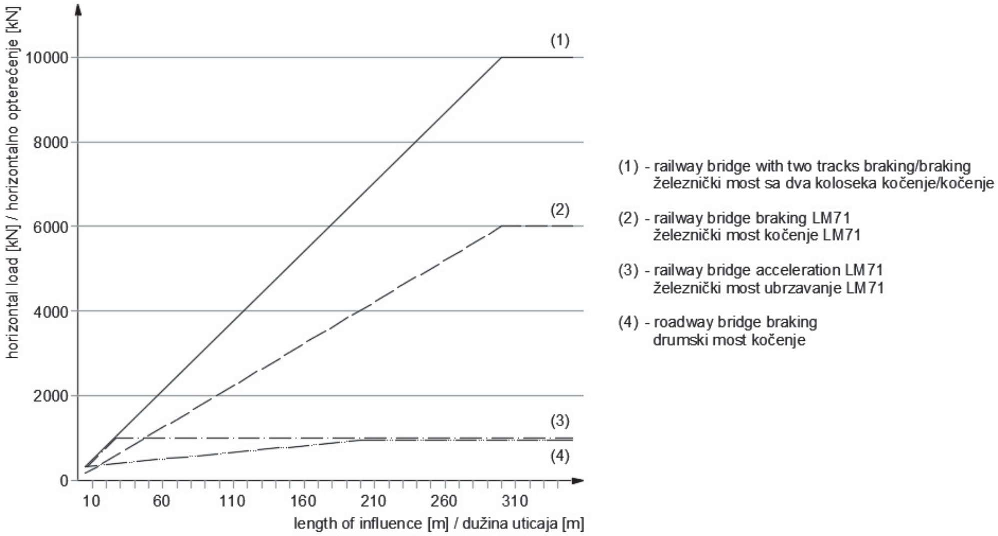
Trzaj pri kočenju koji nastaje kratko pre zaustavljanja

Figure 9 shows the horizontal load of the track under breaking and acceleration of the vehicle. For the comparison, breaking forces for the road bridge are pesented.

Frictional brakes on railway vehicles operate on the basis of friction, which is in most cases achieved using compressed air. When the brake is activated by the machine operator, the airflow wave progresses with speed of 250-280 m/s. Therefore, breaking the vehicle is applied with a delay - after so-called brake preparation time. Break delay time, especially in the case of long railway vehicles, leads to the occurrence of longitudinal dynamic forces. These forces are the consequence of non-simultaneous breaking of individual railcars, which voza, merodavan je za dimenzionisanje železničkih mostova [7]. Najveći trzaj pri kočenju javlja se pod teretnim vozovima zbog velike sopstvene težine.

generates the pressure forces between them.

Jerk during breaking that occurs shortly before stopping the train is representative for the design of railway bridges [7]. The largest jerk during breaking occurs under freight trains due to their large weights.



Slika 9. Horizontalne podužne sile od kočenja i ubrzavanja vozila [12]
Figure 9. Horizontal longitudinal forces from breaking and acceleration of the vehicle [12]

U skladu sa [5, 9] utvrđene su maksimalne vrednosti sila pri ubrzanju i kočenju železničkih vozila:

– Sila pri ubrzavanju vozila Q_{lak} pri šemama opterećenja 71, SW/0, SW/2 i HSLM:

According to [5, 9], following maximum acceleration and breaking forces for railway vehicles have been determined:

– Acceleration force of vehicle Q_{lak} for load models 71, SW/0, SW/2 and HSLM:

$$Q_{lak}=33 \text{ kN/m} * L_{lak} [\text{m}] \leq 1000 \text{ kN}, \quad (1)$$

– Sila kočenja pri šemama opterećenja 71, SW/0 i HSLM,

– Breaking force Q_{lbk} for load models 71, SW/0 and HSLM:

$$Q_{lbk}=20 \text{ kN/m} * L_{lbk} [\text{m}] \leq 6000 \text{ kN}, \quad (2a)$$

odnosno pri šemi opterećenja SW/2:

and for load model SW/2:

$$Q_{lbk}=35 \text{ kN/m} * L_{lbk} [\text{m}] \quad (2b)$$

Maksimalna dužina uticaja L_{lbk} bira se do 300 m kako bi se sprečila pojava sila kočenja koje su veće od 6000 kN (600 t). Štaviše, treba uzeti u obzir da dužina teških teretnih vozova (2000 t i više) ne prekoračuje 300 do 400 m u opštem slučaju, zbog ograničenja zatezanja kuke kvačila pri pokretanju vozila. Usled razvoja sistema kočenja i tehnologije prenosa može biti neophodno da se u proračunu koriste veći uticaji od kočenja u određenim okolnostima. Uobičajene vrednosti dužina uticaja i sila kočenja i ubrzavanja prikazane su u tabeli 5.

U proračunu se koristi sigurnosna temperaturna razlika ΔT_s kako bi se uzela u obzir odstupanja uticaja usled:

– sila kočenja,

– sila završnog pritezanja koje deluje na nožicu kontinualno zavarenih šina,

– bočnih sila.

Sigurnosna temperaturna razlika treba da osigura stabilnost koloseka od bočnog izbacivanja. U tabeli 6 prikazane su vrednosti ΔT_s u zavisnosti od brzine vožnje

Maximum impact length L_{lbk} should be up to 300 m in order to prevent occurrence of brake forces larger than 6000 kN (600 t). Furthermore, it should be taken into account that length of heavy freight trains (that weighs 20000 kN and more) do not exceed 300 m to 400 m in general, due to the limited stretching of the coupler at train start-up. Due to the development of breaking and transmission technologies, it would be necessary to account larger impact of breaking under certain circumstances. The usual values of the impact lengths and the breaking and acceleration forces are shown in Table 5.

Safety temperature difference ΔT_s is used in calculation in order to take into account the uncertainty of:

– breaking forces,

– final clamping forces applied to the foot of continuous welded rails, and

– lateral forces.

The safety temperature difference should ensure the stability of the track from buckling. Table 6 shows the values of ΔT_s depending on the driving speed [7]. In

[7]. Takođe, vrednosti ΔT_s u tabeli 6 obuhvataju i uticaj elektromagnetne kočnice koja je ugrađena u vozilo ICE3 (slika 10).

addition, ΔT_s values in Table 6 include the influence of the electromagnetic rail brakes that are installed on the ICE3 train (Figure 10).

Tabela 5. Karakteristike opterećenja od kočenja i ubrzavanja
Table 5. Parameters of breaking and acceleration load

Type of Track (Tip koloseka)	*Acceleration loads* (Opterećenje od ubrzavanja)		*Braking loads* (Opterećenje od kočenja)	
	Magnitude of Load (Intenzitet opterećenja)	*Loaded length* (Dužina opterećenja)	*Magnitude of Load* (Intenzitet opterećenja)	*Loaded length* (Dužina opterećenja)
High-speed railway (Pruga za velike brzine)	33 kN/m/*track* 33 kN/m/kolosek	33 m	20 kN/m/*track* 20 kN/m/kolosek	400 m
Normal railway (Konvencionalna pruga)	24 kN/m/*track* 24 kN/m/kolosek	33 m	12 kN/m/*track* 12 kN/m/kolosek	300 m

Slika 10. Elektromagnetna kočnica za ICE3 vozilo
Figure 10. Electromagnetic rail brake on the ICE3 train

Tabela 6. Sigurnosna temperaturna razlika ΔT_s u zavisnosti od brzine vožnje [7]
Table 6. Safety temperature difference ΔT_s depending on the driving speed [7]

V [km/h]	≤80	100	120	140	160	230	>230
ΔT_S [^{o}C]	10	20	25	30	40	50	60

6 DODATNI NAPONI U ŠINI

Dozvoljeni dodatni naponi pritiska u šini usled interakcije kolosek/most treba da budu [1, 4, 9]:

– ≤ 72 N/mm^2 za kolosek u zastoru od tucanika,
– ≤ 92 N/mm^2 za kolosek na čvrstoj podlozi;

Dokazivanje dopuštenog dodatnog napona pritiska izvodi se na osnovu kriterijuma izbacivanja koloseka sa kontinualno zavarenim šinama.

Kritično povećanje temperature u šini koje može da dovede do izbacivanja koloseka iznosi cca. 122°C prema [3, 13], pod sledećim pretpostavkama:

– greška u smeru koloseka 4,5 mm za pruge za velike brzine,
– dinamički otpor poprečnom pomeranju koloseka w_Q=10 kN/m;
– kolosek sa šinama 60E1, betonski pragovi B70.

Prema razmatranjima u radu [7], ukoliko se usvoji:

– temperaturna promena 38°C između temperature u šini i temperature pri završnom pritezanju kontinualno zavarene šine,
– sigurnosna temperaturna promena ΔT_s=50°C (u

6 ADDITIONAL STRESSES IN THE RAIL

The permissible additional pressure in the rail due to the track/bridge interaction should be [1, 4, 9]:

– ≤ 72 N / mm^2 for ballasted track,
– ≤ 92 N / mm^2 for a slab track.

The permissible additional pressure should be calculated using track buckling criteria for CWRs. The critical temperature increase in the rail, which can lead to track buckling, is approximately 122°C according to [3, 13] under the following assumptions:

– track alignment deviation equals 4,5 mm for high speed lines,
– dynamic resistance to the lateral displacement of the track w_Q = 10 kN/m, and
– track with 60E1 rail profile and B70 concrete sleepers.

According to the discussions in [7], if following is adopted:

– temperature difference between rail temperature and temperature at the final tightening of CWR equals 38°C, tabeli 6 ova vrednost odgovara brzini do 230 km/h), izduženje šine pod uticajem opterećenja od saobraćaja koje odgovara temperaturnoj promeni od 3°C,

dobija se rezerva temperaturne promene primenom jednačine (3).

– safety temperature change equals ΔT_s = 50°C for high speed traffic (in table 6 this value corresponds to speeds up to 230 km/h), and

– rail elongation under the influence of traffic load corresponds to the temperature change of 3°C,

temperature change reserve is obtained using equation (3).

$$\Delta T_R = 122^o C - (38^o C + 50^o C + 3^o C) = 31^o C \quad (3)$$

Razlika od 31°C može da se proračuna i izrazi preko dodatnog napona pritiska u šini od 72 N/mm^2 što osigurava da ne dođe do izbacivanja koloseka u stranu.

Dozvoljena vrednost dodatnog napona zatezanja u šini usled interakcije most/kolosek treba da bude ≤ 92 N/mm^2 (važi za kolosek u zastoru od tucanika i kolosek na čvrstoj podlozi) [2].

Gore pomenute dozvoljene vrednosti dodanih napona pritiska i zatezanja važe za kolosek u zastoru od tucanika samo pod sledećim pretpostavkama:

– šine 60E1 sa zateznom čvrstoćom ≥ 880 N/mm2;
– radijus koloseka R ≥ 1500 m;
– betonski pragovi B70 W na rastojanju max. 65 cm (ili slični tip praga sa najmanje jednakom težinom);
– najmanje 30 cm zbijenog zastora ispod pragova.

U slučaju koloseka na čvrstoj podlozi zahteva se da je šina 60E1 sa zateznom čvrstoćom ≥ 880 N/mm^2.

Tabela 7. prikazuje dopuštene dodatne napone pritiska i zatezanja za kolosek u pravcu i krivini.

A difference of 31°C could be calculated and expressed through an additional stress pressure in the rail of 72 N/mm^2, which ensures that the track buckling does not occur.

The permissible value of the additional tensioning stress in the rail due to bridge/track interaction should be less or equal 92 N/mm^2, which applies to both ballasted track and slab track [2].

The aforementioned permissible values of the additional pressure and tensile stresses apply only under the following assumptions:

– 60E1 rail profile with tensile strength ≥ 880 N/mm^2,
– radius of the track R ≥ 1500 m,
– B70 W concrete sleepers at a distance up to 65 cm (or similar type of sleepers with similar weight), and
– at least 30 cm of compacted ballast under sleepers.

In the case of slab track, 60E1 rail profile with tensile strength greater or equal 880 N/mm^2 is required.

Table 7 shows the permissible additional stresses and tensile stresses for the straight and curved track.

Tabela 7. Dodatni naponi u šini [2, 9]
Table 7. Additional stress in the rail [2, 9]

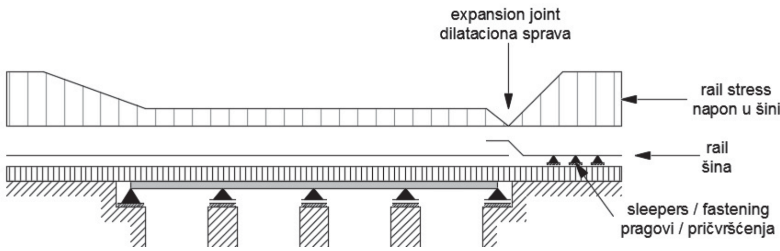
Addition rail stress (Dodatni napon u šini)	*Loads* (Opterećenja)	*Criteria* (Kriterijum)	
		Ballasted track (Kolosek u zastoru od tucanika)	*Slab track* (Kolosek na čvrstoj podlozi)
Pressure stress (Napon pritiska)	*Temperature* (Temperatura) *Acceleration / braking* (Ubrzavanje / kočenje) *Vertical loads* (Vertikalno opterećenje)	R≥1500 m: 72 N/mm^2	92 N/mm^2
		R≥700 m: 58 N/mm^2	
		R≥600 m: 54 N/mm^2	
		R≥300 m: 27 N/mm^2	
Tension stress (Napon zatezanja)		92 N/mm^2	

7 DILATACIONE SPRAVE U KOLOSEKU NA MOSTU

Ukoliko usled topografije ili drugih ograničenja ne može da se održi maksimalna dilataciona dužina 60 m odnosno 90 m, neophodno je da se redukuju dodatna naprezanja u šinama na neki drugi način. Jedan od načina je da se ugrade dilatacione sprave u kolosek iznad krajnjih pokretnih oslonaca mosta, kako bi se redukovala naprezanja u šinama koja nastaju usled pomeranja konstrukcije gornjeg stroja mosta (slika 11).

7 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 (Fig. 11).



Slika 11. Naprezanje u šini na (pokretnom) kraju mosta sa dilatacionom spravom u koloseku
Figure 11. Strain in the rail at the movable end of the bridge with rail expansion joint

Ipak, dilatacione sprave treba izbegavati zbog:
- velike cene proizvodnje i ugradnje,
- velikih troškova održavanja,
- nepovoljnog uticaja na komfor vožnje.

Slika 12 prikazuje diskontinuitet na voznoj površi na glavi šine u zoni dilatacione sprave.

However, rail expansion joints should be omitted due to:
- high price of production and installation,
- high maintenance costs, and
- adverse influence to the driving comfort.

Figure 12 shows the discontinuity on the running surface of the rail head in the zone of expansion joint.

Slika 12. Diskontinuitet vozne površi u zoni dilatacione sprave
Figure 12. Discontinuity of the running surface of the rail head at the expansion joint

Kako bi se smanjila cena, dilatacione sprave su standardizovane prema dužini dilatiranja, kao što je prikazano u tabeli 8. U svakom slučaju, neophodno je obratiti posebnu pažnju na komplikovanu ugradnju i održavanje.

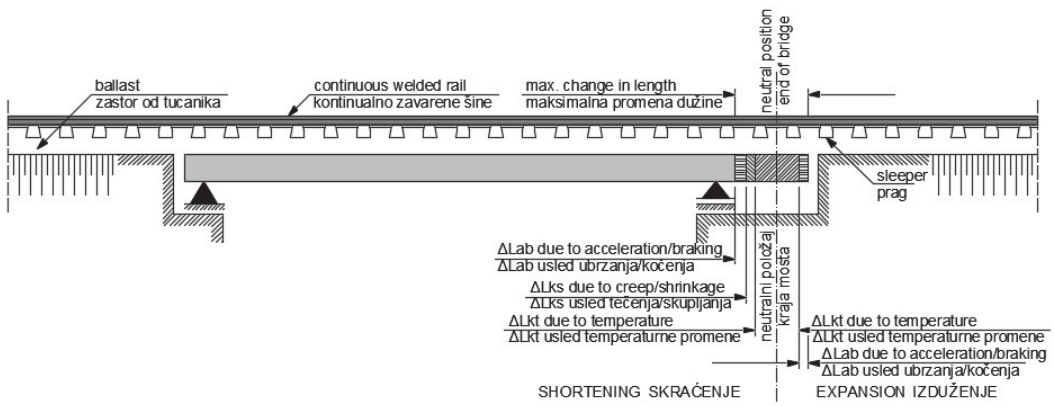
In order to reduce price, it is necessary to standardise expansion joints according to their expansion length as it is shown in Table 8. In any case, special attention should be drawn to the complicated installation and maintenance.

Tabela 8. Standardni tipovi dilatacionih sprava na železnici u Nemačkoj [7]
Table 8. Standard types of expansion joints used on railways in Germany [7]

No. (Br.)	*Label* (Oznaka)	*Expansion length* (Dužina dilatiranja)
1	54/60-*200 for wooden or concrete sleepers* (54/60-200 za drvene ili betonske pragove)	200 mm
2	54/60-340 *for wooden or concrete sleepers* (54/60-340 za drvene ili betonske pragove)	340 mm
3	60-500 *for wooden or concrete sleepers* (60-500 za drvene ili betonske pragove)	500 mm
4	30-830 *for concrete sleepers* (30-830 za betonske pragove)	700 mm

Ukupna podužna pomeranja konstrukcije gornjeg stroja železničkog mosta prikazana su na slici 13.

The total longitudinal displacements of the railway bridge deck are shown in Figure 13.



Slika 13. Parametri za određivanje ukupnih podužnih dilatiranja mosta
Figure 13. Parameters for designing the total longitudinal displacements of the bridge

8 DISKUSIJA I ZAKLJUČAK

Železnice u Srbiji su deo evropske železničke mreže i njihov razvoj treba da bude u skladu sa evropskom transportnom politikom. Dva evropska saobraćajna koridora prolaze kroz Srbiju: Dunavski koridor VII i drumsko-železnički Koridor X. Održiva transportna politika u Srbiji definiše pravce razvoja sa ciljem unapređivanja železničkog saobraćaja [14]. Glavni cilj za železnički koridor X kroz Srbiju je rekonstrukcija postojećih železničkih pruga, što obuhvata građenje drugog koloseka na deonicama jednokolosečnih pruga i elektrifikaciju radi osposobljavanja železničkog koridora za brzine vozova do 200 km/h. Jedan od preduslova za dostizanje ovog cilja je harmonizacija srpske tehničke regulative u oblasti železničke infrastrukture, uključujući i mostove [15].

Razmatranja u ovom radu treba da stvore osnovu za harmonizaciju tehničke regulative u oblasti železničkih mostova kako bi se zadovoljili zahtevi interoperabilnosti.

Upravljanje problemima interakcije konstrukcija koloseka i mosta podrazumeva da most u potpunosti ispunjava svoju funkciju i prihvata opterećenje od konstrukcije koloseka bez njenog oštećenja. Ovo važi kako za kolosek na čvrstoj podlozi, tako i za kolosek u zastoru od tucanika na mostu.

Za istraživanje interakcije kolosek/most treba da bude poznato sledeće:

- statički sistem mosta,
- ponašanje ležišta,
- ponašanje oslonaca (ležišta i stubova),
- ukupna krutost oslonaca (ležišta i stubova),
- ponašanje gornjeg stroja mosta pri savijanju.

Slučajevi koji bi mogli da dovedu do interakcije između koloseka i konstrukcije gornjeg stroja mosta su:

– temperaturno pomeranje konstrukcije gornjeg stroja mosta u slučaju kada su šine u koloseku kontinualno zavarene,

– temperaturno pomeranje konstrukcije gornjeg stroja mosta i šina ukoliko je ugrađena dilataciona sprava u koloseku,

– horizontalne sile usled ubrzavanja/kočenja vozila,

– zaokretanje krajeva mosta usled savijanja konstrukcije gornjeg stroja mosta pod vertikalnim opterećenjem,

8 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 [14]. 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 electrification in order to enable railway corridor for train speeds up to 200 km/h. One of the prerequisites to achieve this goal is harmonisation of Serbian technical regulations in the field of railway infrastructure [15].

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 entirely fulfils 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), and
- 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

– pomeranje konstrukcije gornjeg stroja mosta usled tečenja i skupljanja betona,

– podužno pomeranje oslonaca mosta usled temperaturne promene u stubovima.

Treba napomenuti da u slučaju koloseka sa kontinualno zavarenim šinama, promena temperature u šinama ne dovodi do pomeranja koloseka i zbog toga ne dolazi do interakcije sa mostom.

Takođe, sile usled ubrzavanja/kočenja vozila treba kombinovati sa odgovarajućim vertikalnim opterećenjima na mostu. U slučaju mosta sa više koloseka, moraju se kombinovati sile ubrzavanja na jednom koloseku sa silama kočenja na drugom koloseku. Uzimaju se u obzir samo dva koloseka.

Uticaj vertikalnog opterećenja mora da se ispita u pogledu zaokretanja i pomeranja krajeva konstrukcije gornjeg stroja mosta. Ispituju se uticaji za svaki krajnji oslonac konstrukcije gornjeg stroja mosta.

Ukupan napon u kontinualno zavarenim šinama određuje se na osnovu proračuna stabilnosti koloseka. Ukupan napon uključuje dodatni napon u šinama usled interakcije.

Pomeranje konstrukcije gornjeg stroja mosta i koloseka mora ostati u dozvoljenim granicama, kako bi se sprečila dekonsolidacija tucanika u zastoru i kako se ne bi pojavili veliki podužni naponi u šinama.

Dilatacione sprave na mostu treba izbegavati ukoliko je to moguće. U svakom slučaju, dilataciona sprava se postavlja na slobodnom kraju gornjeg stroja mosta ukoliko ukupno dodatno naprezanje šine i/ili pomeranja prekoračuju propisane vrednosti.

Ako se iz bilo kog razloga menjaju uslovi koloseka (na primer, radovi na održavanju, prekidanje kontinualno zavarenih šina ugradnjom mehaničkog spoja) moraju se prilagoditi uslovi odvijanja saobraćaja na mostu (na primer, zabrana upotrebe kočnica).

Institut za standardizaciju Srbije usvojio je EN standarde u oblasti mostova (tabela 1) [18]. Dakle, neophodna je harmonizacija tehničke regulative u oblasti železničkih mostova kako bi se zadovoljili zahtevi interoperabilnosti.

– 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 breaks).

Institute for standardisation of Serbia adopted a large number of EN standards in the field of bridges (Table 1) [18]. Therefore, it is necessary to harmonise technical regulations in the field of railway bridges in order to meet the requirements of interoperability.

ZAHVALNICA

Ovaj rad podržalo je Ministarstvo prosvete, nauke i tehnološkog razvoja Republike Srbije, pod brojem 36012: „Istraživanje tehničko-tehnološke, kadrovske i organizacione osposobljenosti Železnica Srbije sa aspekta sadašnjih i budućih zahteva Evropske unije”.

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".

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REZIME

ŽELEZNIČKI MOSTOVI NA INTEROPERABILNIM PRUGAMA - ASPEKT INTERAKCIJE KOLOSEK/MOST

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Institut za standardizaciju Srbije usvojio je EN standarde u oblasti mostova kao srpske standarde. Nažalost, još uvek nije urađena tehnička regulativa zasnovana na primeni usvojenih EN standarda u oblasti mostova. U radu se prikazuju zahtevi za železničke mostove koji su zasnovani na EN standardima, UIC objavama i na nemačkoj tehničkoj regulativi. Primarno se obrađuje aspekt interakcije kolosek/most. Predstavljeni su parametri interakcije kolosek/most, principi proračuna, kao i pregled otvorenih pitanja. Kao najznačajniji parametri konstrukcije mosta razmatrani su: dužine dilatiranja mosta, krutost konstrukcije donjeg stroja mosta, kao i krutost na savijanje i visina konstrukcije gornjeg stroja mosta. Pored toga, posebno su analizirani uticaji vertikalnog opterećenja, temperaturnih promena, kao i ubrzavanja/kočenja vozila na pomenutu interakciju. Zaključci rada se odnose i na kolosek u zastoru od tucanika i na kolosek na čvrstoj podlozi. Cilj rada je stvaranje osnove za harmonizaciju tehničke regulative u Srbiji sa evropskom regulativom kako bi se ispunili zahtevi interoperabilnosti.

Ključne reči: železnica, interoperabilnost, most, kolosek, interakcija, proračun.

SUMMARY

RAILWAY BRIDGES ON INTEROPERABLE LINES – ASPECT OF TRACK/BRIDGE INTERACTION

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The Institute for Standardization of Serbia has adopted a large number of EN standards in the field of bridges as Serbian standards. Unfortunately, technical regulations based on the implementation of the adopted EN standards in the field of bridges are still not made. The paper presents requirements for railway bridges based on EN standards, UIC leaflets and German technical regulations. The aspect of track/bridge interaction is primarily considered. The parameters of track/bridge interaction, principles of calculation, as well as the overview of open points are presented. As the most important parameters of the bridge structure were considered: bridge expansion length, stiffness of the bridge substructure, as well as the bending stiffness and height of the bridge deck. Further, the effects of vertical load, temperature changes, and acceleration/breaking of the vehicle on the mentioned interaction are especially analysed. In addition, the conclusions of the paper apply to both ballasted track and slab track. The aim of the paper is to create a basis for the harmonisation of technical regulations in Serbia with European regulations in order to meet the requirements of interoperability.

Key words: railway, interoperability, bridge, track, interaction, calculation.