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23–25 May 2016, Šibenik, Croatia

Road and Rail Infrastructure IV

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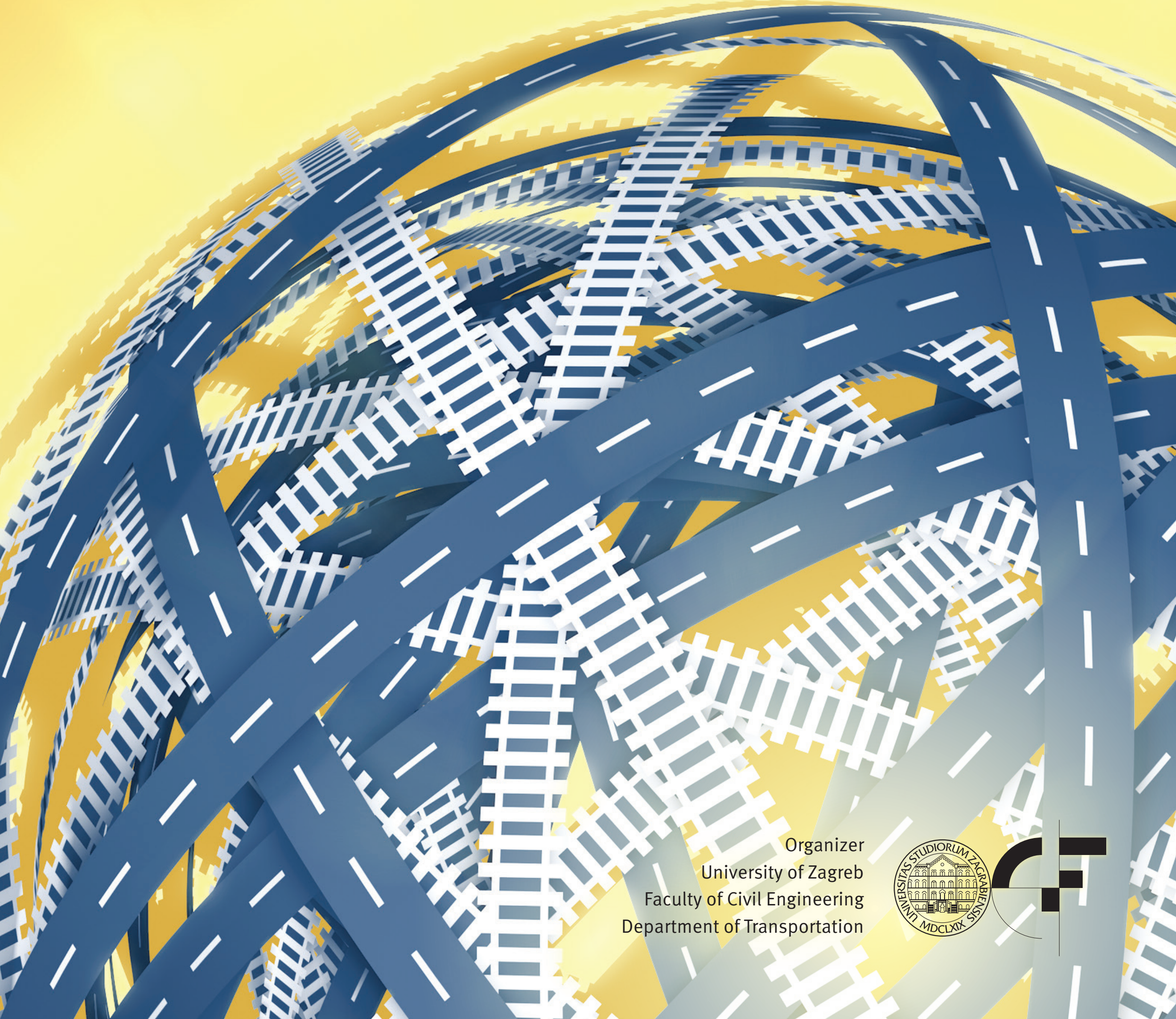

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INTERACTION BETWEEN CONTINUOUS WELDED RAIL AND BRIDGES WITH RELATIVELY LARGE EXPANSION LENGTH

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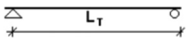
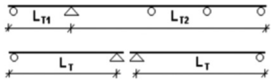
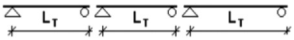
Abstract

Regarding indisputable savings in maintenance costs continuous welded rail is installed in almost all track sections which are renewed or newly constructed. A need to solve the interaction between the track and bridge preferably without expansion joints has arisen. A complex evaluation of combined response to variable actions is not required according to the Czech national regulation if the track is renewed and the bridge expansion length is within limits. Exceptions are often allowed for bridges whose expansion length exceeds the limits. Good experience supports an increase of limits but theoretical analysis and structure monitoring are desirable. Five bridge structures – steel, concrete, combined and different deck – with ballast, with timbers or direct fastening, had been monitored for three years in all climate conditions. The displacement of track and bridge was surveyed by precise geodetic methods. The longitudinal reactions in bridge fixed bearings were measured for the bridge. Finite element models were built for all the monitored bridges. The backward analyses were carried out for all surveying epochs in the aim to define basic parameters of combined response – bilinear longitudinal resistance of track and the longitudinal stiffness of bridge support. The results serve both to evaluate the parameters defined in European standard EN 1991-2 for ballasted track and to complete the parameters for non-ballasted track.

1 Introduction

Nowadays continuous welded rail regarding indisputable savings in maintenance costs is installed almost in all track sections which are renewed or newly constructed. Recently gained experience with construction, service and maintenance of continuous welded rail allows application even in very small radius curves, in which construction of continuous welded rail was not permitted before.
A need to solve the interaction between track and bridge preferably without expansion joints has arisen simultaneously. A complex evaluation of combined response on variable actions is not required according to the Czech national regulation [1] if the track is renewed and the bridge expansion length is within limits. The limits of expansion length were defined based on analyses published in [2]. The analyses comprised both the theoretical description of track bridge interaction and the monitoring of behaviour of selected bridge structures in situ. The mathematical model was based on the linear expression of the track longitudinal resistance in dependence on the track displacements. Other parameters included into the calculation of the track bridge interaction were adapted, eg. equivalent thermal expansion coefficients for different types of bridge structures and bridge decks. The comprehensive assessment system was expressed in the table of admissible expansion lengths, see Tab. 1.

Table 1 Permissible expansion lengths according to the Czech national standard

Case no.	Arrangement of structures and bearings	Rail	Steel structure, ballasted deck	
			L_T [m]	
			Sleepers	
			wooden	concrete
1		60 E1(2)	110	80
		49 E1	85	60
2		60 E1(2)	108	74
		49 E1	75	51
3		60 E1(2)	61	44
		49 E1	55	40

Very good experience was gained with the design and evaluation procedure defined in the Czech national regulation [1]. As long as the admissible lengths were respected no failures originated from the track bridge interaction have occurred in service over the years. Exceptions are often allowed for bridges which expansion length exceeds the limits. Good experience supports an increase of limits but theoretical analysis and structure monitoring are desirable. The theoretical base of track bridge interaction is described for example in [3], some essential parameters can be found in [4]. The assessment of the combined response of structure and track to variable actions is precisely defined in the UIC Code 774-3 [5] and the Eurocode EN 1991-2 [6] which were issued later on. The European standards comprise only bridges with ballasted deck, rail UIC 60 (60 E1, 60 E2) and track of radius 1500 m and higher. Other bridges still have to be evaluated according to the national annex of the standard or according to the national standards.
The paper is aimed at the monitoring of bridges with relatively large expansion length regarding the national standard [1], particularly in the assessment of longitudinal track resistance.

2 Track bridge interaction monitoring

Five bridge structures – steel, concrete, combined of different types of the bridge deck – with ballast, with bridge timbers or direct fastening had been monitored for three years in all climate conditions. The displacement of track and bridge were surveyed by precise geodetic methods. The longitudinal reactions in bridge fixed bearings were monitored for the selected bridge.

2.1 Displacement surveying

The bridges were monitored for 3 years (2013 – 2015) in 8 geodetic surveying epochs each bridge. 40 surveying epochs in total were carried out on the 5 selected bridges (bridges are numbered for the purpose of this paper):

1) Truss bridge, three simple supported decks, L_T = 16,0/29,8/16,0 m (permissible 25 m), overhead open deck, bridge timbers – flat support, rail 49 E1, rail fastening KS (Skl 24)
2) Steel bridge, multiple-span continuous deck, L_T = 80,3 m (permissible 60 m), ballasted track, rail 49 E1, rail fastening W14, concrete sleepers
3) Steel bridge, simple supported deck, L_T = 30 m (permissible 20 m), floor ballastless deck, direct fastening, rail 49 E1, rail fastening KS (Skl12)
4) Truss bridge, simple supported deck, L_T = 48,6 m (permissible 70 m), floor open deck, bridge timbers – centric support, rail R 65, KS (Skl24)
5) Composite steel concrete bridge, multiple-span continuous deck, L_T = 85,5 m (permissible 60 m), ballasted track, 60E1, W14, concrete sleepers

Survey points, which were monitored by the terrestrial geodetic method [7], were marked along the bridge length on the both rails as well as on the particular bridge structure. Besides the displacement current temperatures of the rails and the bridge structure were monitored. The rail temperature was measured on four points along the rail cross section. The temperature of the bridge was measured on several points along the height of the structure. Average rail and bridge temperature values for the rails and the bridge were taken into an evaluation. The relative displacement of each point on the both rails and the bridge structure were evaluated in comparison with the state in the initial stage of the surveying. The example of surveying results and its evaluation is presented in Chap. 3.

2.2 Longitudinal reactions in fixed bridge bearings

In addition, longitudinal forces acting to the fixed bridge bearings were monitored for the bridge No. 1. They were measured indirectly by strain gages installed on the steel bridge bearings. That is why a static analysis of the bridge bearings by finite element methods was carried out. Dimensions of the particular bridge bearings were measured in site for this purpose. Points, in which the strain gages were installed, had been determined on base of the static analysis, see Fig. 1. This allows recalculation of the strain to the longitudinal forces acting on the bridge bearings.

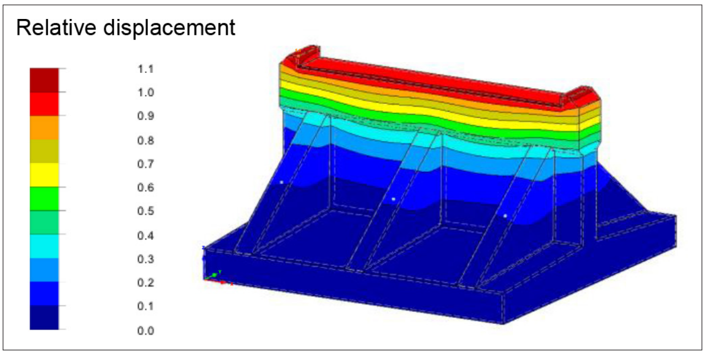


Figure 1 FEM analysis of the steel bridge bearing

The strain gages were installed on two fixed bearings of the bridge No. 1 in July 2013. Eight strain gages in pairs were installed in total, but one strain gage was damaged during the measurement. A logger, measuring and recording values of strain and temperature, was inserted into a special steel box hanged on the bridge structure.

The monitoring was carried out continuously until June 2014, when the cables connecting the strain gages and the temperature sensors were destroyed by vandals. Values of the individual gages and sensors were taken every 5 minutes. The monitoring of strain and temperature had been carried out for almost the whole year including the lowest and the highest temperatures periods. The records corresponding to the geodetic surveying was carried out, was evaluated separately. The evaluation of longitudinal forces acting on the fixed bridge bearings were used in numerical analyses to make it more accurate.

The calculated and measured forces have the same tendency. However, differences between predicted forces determined by the numerical analyses and measured forced for some pairs of strain gages were observed. These differences can be explained by bearing clearances up to 5 mm which are asymmetrical on the particular bearing. An asymmetry of acting forces on the bridge structure due to the fact the track on bridge is in curve means another influence. An example of evaluation results for longitudinal forces see in Tab. 2. Calculated forces correspond to the state of the track bridge interaction during the geodetic surveying.

Table 2 Evaluation of longitudinal forces action on the fixed bridge bearings

Strain gage No.	Measured force [kN]	Calculated force [kN]	Difference [kN]
1	333,04		171,21
4			
2	160,99	161,83	-0,16
3			
6	96,81		-65,02
7			

3 Numerical analyses

Finite element models were built for all the monitored bridges. Backward analyses were carried out for all surveying epochs with the aim to define basic parameters of the combined response – the bilinear longitudinal resistance of track and the longitudinal stiffness of bridge support. Received results serve both to evaluate parameters defined in European standard EN 1991-2 for ballasted track and to complete parameters for non-ballasted track.

3.1 Finite elements models of track bridge interaction

Due to the fact that the longitudinal displacements caused by the temperature load were monitored, finite element models of track and bridge were built as a 2D beam. Only the effects caused by the extreme temperature changes in summer and winter were analysed. The effect of traction or breaking forces and the effect of vertical load were omitted.
The beam elements for the bridge and the track were used in the model. The basic parameters of beam elements: cross section area, moment of inertia, Young's modulus, temperature and coefficient of thermal expansion. The longitudinal resistance between bridge and track and between embankment and track was modelled as bilinear by special spring elements. The function describing the longitudinal resistance comprises initial elastic resistance [kN/mm of displacement per m of track] and then plastic shear resistance [kN per m of track] defined by displacement u_0 as shown in Fig. 2. The longitudinal resistance was taken into calculations in the value for unloaded track.

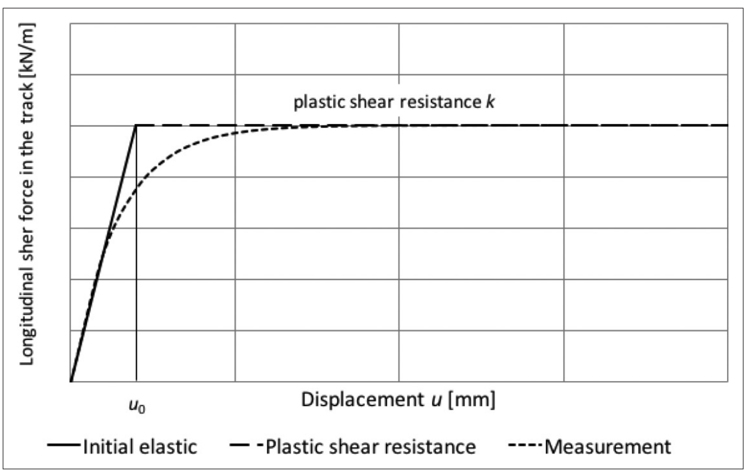


Figure 2 Variation of longitudinal shear force with longitudinal track displacement

The general finite element model shown in Fig. 3 contains besides beam and spring elements also elements representing support stiffness at abutments or pillars. The model allows to take into account any number of parallel tracks or to add or to remove pillars.

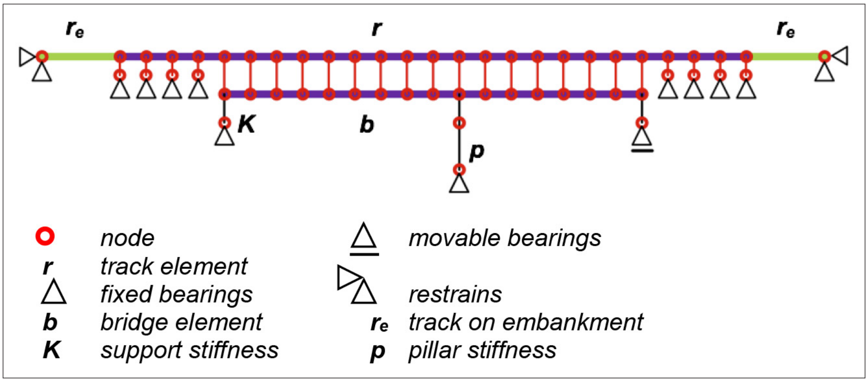


Figure 3 General finite element model of the track bridge interaction

3.2 Measured data assessment

The finite element models were used in backwards analyses with the aim to determine parameters of track bridge interaction. In the first phase of results comparison of monitoring and the numerical analyses of the track bridge interaction necessary parameters were used according to the recommendation published in [5] and [6]. In the second phase the parameters were varied by an iterative procedure to reach as close as possible compliance between the measurements and the calculations of track and bridge displacement. Following parameters were varied:

- plastic shear resistance k;
- displacement u_0 for which the value of plastic shear resistance is reached;
- coefficient of thermal expansion of the bridge structure α_B;
- support stiffness K;

The displacement u_0 was varied in the step of 0.5 mm, the value of plastic shear resistance was varied in the step of 5 kN/m. The temperature loads were considered according to the measured values. That meant that for every bridge structure 8 temperature states were assessed and evaluated. The assessment was always carried out immediately after the particular geodetic surveying had been evaluated.
An evaluation example of the track bridge interaction parameters is shown in Fig. 4. The values comparison of the track longitudinal resistance recommended according to the standards and the final estimated values are listed in Tab. 3.

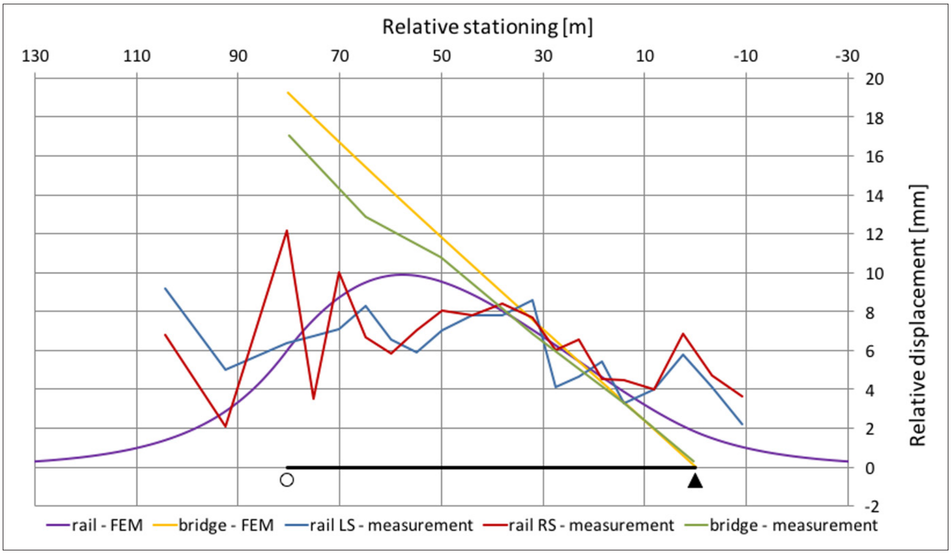


Figure 4 Example of displacements evaluation, bridge No. 2

Table 3 Results of investigation – unloaded track

Bridge structure Bridge deck	Plastic shear resistance k		Displacement u_0	
	observed	rec.[1]	observed	rec.[2]
	[kN/m]	[kN/m]	[mm]	[mm]
1. Truss bridge Overhead open deck Bridge timbers – flat support	40	–	0,5	0,5
2. Steel bridge Ballasted deck	20	20 – 40	2,0	2,0
3. Steel bridge Floor ballastless deck Direct fastening	40	–	0,5	0,5
4. Truss bridge Floor open deck Bridge timbers – centric support	5	–	0,5	0,5
5. Combined concrete – steel bridge Ballasted deck	10	20 – 40	2,0	2,0

[1] EN 1991-2, 6.5.4.6.1 Simplified calculation method; [2] UIC 774-3, 1.2.1.2 Bilinear behavior of the track

4 Conclusions

The acquired parameters of track longitudinal resistance, which are essential for the evaluation of track bridge interaction, allow to make analyses of existing or designed bridges more precise. The measured parameters of longitudinal resistance do not differ significantly from the recommended values specified in UIC Code 774-3 and Eurocode EN 1991-2. Acquired knowledge on the track bridge interaction enables a gradual transition from the national methodology of assessment to the methodology according to the European standards for existing bridges with ballastless deck.

The monitoring and the FEM analyses were completed by a simplified mathematical model to calculate combined response. The model was compiled on the basis of the monitoring results and the numerical analyses. The simplified model enables the infrastructure manager to calculate the combined response of the particular bridge design without the need to build a complex numerical model. Results of the presented research provide a tool for a reasoned decision on the installation of continuous welded track on bridges which expansion length is over the current limits specified in the Czech national regulation. The description of the analytical tool is beyond the extent of this paper.

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