IX

Effect of Fabrication Imperfections upon the Design Safety of Steel Bridges

Effet des imperfections de fabrication sur la sécurité de dimensionnement des ponts en acier

Einfluss der Fertigungsimperfektionen auf die Berechnungssicherheit von Stahlbrücken

JOSEF DJUBEK
Assoc. Prof., Dr. Sc.
Slovak Academy of Sciences
Bratislava, CSSR

IRENA KÁRNÍKOVÁ
Ph. D., Civ. Eng.
Czech Technical University
Prague, CSSR

MIROSLAV ŠKALOUD
Assoc. Prof., Dr. Sc.
Czechoslovak Academy of Sciences
Prague, CSSR

SUMMARY
The contribution sums up the most important results of initial imperfection measurements on four new steel box-girder bridges, and the impact of the measured values and currently proposed admissible tolerances on a reduction of the ultimate strength of the compressed zones of the lower flanges of the above bridges.

RESUME
La contribution résume les résultats les plus importants de mesures imperfections initiales réalisées sur quatre nouveaux ponts en acier. L'effet des valeurs mesurées est comparé avec les tolérances admissibles proposées actuellement pour une réduction de la charge ultime des zones comprimées de la semelle inférieure des ponts.

ZUSAMMENFASSUNG
Der Beitrag fasst die wichtigsten Ergebnisse von an vier neuen Stahlbrücken mit Kastenquerschnitt durchgeführten Messungen zur Ermittlung von Imperfektionen zusammen. Die gemessenen Werte werden den heute als zulässig empfohlenen Toleranzwerten bezüglich einer Reduktion der Tragfähigkeit der Druckzonen der untern Flansche gegenübergestellt.

1. INTRODUCTORY REMARKS

The behaviour of the plate elements of steel structures is significantly affected by the presence of unavoidable initial imperfections resulting from fabrication and erection processes. This effect is particularly pronounced in the case of compression flanges of steel box-girder bridges, where it was one of the reasons of a number of serious accidents.

In order to be able to assess quantitatively the above effect, we are bound to know:

(i) The magnitude of the imperfections occurring on ordinary steel bridges,

(i) The impact of such imperfections on the reduction of the ultimate strength of steel bridges.

2. CAMPAIGN OF MEASUREMENTS OF IMPERFECTIONS ON NEW CZECHOSLOVAK STEEL BRIDGES

To obtain reliable information regarding the first problem, the authors started an extensive campaign of imperfection measurements on four new Czechoslovak steel box-girder bridges. They are: a) the motor-way bridge over the river Oslava at Velké Meziříčí (Fig. 1), b) the railway bridge at Ivančice (Fig. 2), c) the fly-over crossing the railway station Prague - Centre (Fig. 3) and d) the new structure of the Barricade Fighters Bridge over the river Vltava in Prague (Fig. 4).

The initial curvatures of the stiffeners and sheet panels of both webs and flanges were measured. This contribution is confined to the initial imperfections of the lower flanges, since it is in the compressed portions of these flanges where the effect of the unavoidable "dishing" is expected to be most significant.

The results of the statistical evaluation of the initial imperfections measurements on all four bridges are listed in Table 1. The table sums up 448 imperfections of longitudinal stiffeners and 1 617 imperfections of the partial panels of the lower flange. In the first columns of the table, the characteristic dimensions of the flange panels are given, i.e. the length l of the longitudinal ribs between two adjacent transverse stiffeners, the width b of the partial flange panel between two neighbouring longitudinal ribs and the thickness t of the flange sheet. In the next column the value R denotes the s.c. design strength of the used material.

Further the table presents the boundaries of an interval comprising 95 % of all measurements, the sign of the measurements being considered. The statistical analysis of all measured values was carried out on a computer for (i) a normal probabilistic distribution, (ii) a log-normal distribution,

(iii) a distribution of minimum values of type I and (iiii) a distribution of maximum values of type I. As the boundaries for the above distribution curves a little differ from each other, their mean values are given in the table. The boundaries are calculated (i) in absolute values (mm), (ii) in nondimensional parameters (y_o/ℓ , resp. w_o/b).

The last columns of the table give the percentage of those measurements, for which the currently used criteria for admissible tolerances were not satisfied, viz. the value $y_{o max} = \ell/500$ for longitudinal ribs and $w_{o max} = b/250$ for partial flange panels (w_o denotes the amplitude of the "dishing" of partial flange sheet panels between longitudinal ribs and y_o is the amplitude of the initial curvature of the longitudinal stiffeners between two neighbouring transverse beams).

An analysis of the results given in Table 1 shows that
(i) The magnitude of the measured imperfections on the four bridges significantly differ from each other,
(ii) The measured imperfections of the lower flange elements are frequently larger than the currently proposed admissible tolerances $y_{o max} = \ell/500$ and $w_{o max} = b/250$. The number of measurements exceeding the above tolerances varried from 1 % to 76,9 %.

3. EFFECT OF THE INITIAL CURVATURE ON THE LIMIT STATE OF THE COMPRESSION FLANGES OF THE INVESTIGATED BRIDGES

Using the large deflection theory, the authors determined – for the bridges under consideration – the impact of the measured geometrical imperfections on a reduction of the ultimate strength of the compressed zones of the lower flanges. The limit state of the flange is defined by the onset of membrane plastification at the longitudinal edges of the flange. This definition of the limit state was adopted considering the effect of variable repeated and dynamic loading on bridges.

The main results of the analysis are given in Table 2, where m_{1N} denotes the total reduction coefficient and m_{2N} the local one. Further the flange limit load reduction in % is presented.

For the sake of comparison, the authors also evaluated the effect of (i) normative tolerances (such as they are currently proposed for steel bridges, i.e. $w_{o max} = b/250$ and $y_{o max} = \ell/500$) and (ii) initial imperfections equal to 200 % of the aforesaid normative tolerances.

The results of the analysis are also presented in Table 2. It can be seen there that a further enlargement of initial curvature does not affect considerably (in the studied four cases) the reduction of the flange limit load.

For all four bridges, the writers also determined the reduction factors m_{1N} and m_{2N} on the assumption of an "ideal" flange without initial curvature. The corresponding results are as follows:

Velké Meziříčí:

$m_{1N} = 1,0$; $m_{2N} = 0,9083$;   reduction 9,1 %

Ivančice:

$m_{1N} = 1,0$; $m_{2N} = 0,9003$;   reduction 10 %

Prague – Centre:

$m_{1N} = 1,0$; $m_{2N} = 0,8480$;   reduction 15,2 %

Barricade Fighters Prague:

$m_{1N} = 1,0$; $m_{2N} = 0,9735$;   reduction 2,6 %

An inspection of the obtained results show that the effect of the initial imperfections on the limit load depends on the geometrical and material characteristics of the studied flange panels. In some cases, this effect can be significant.
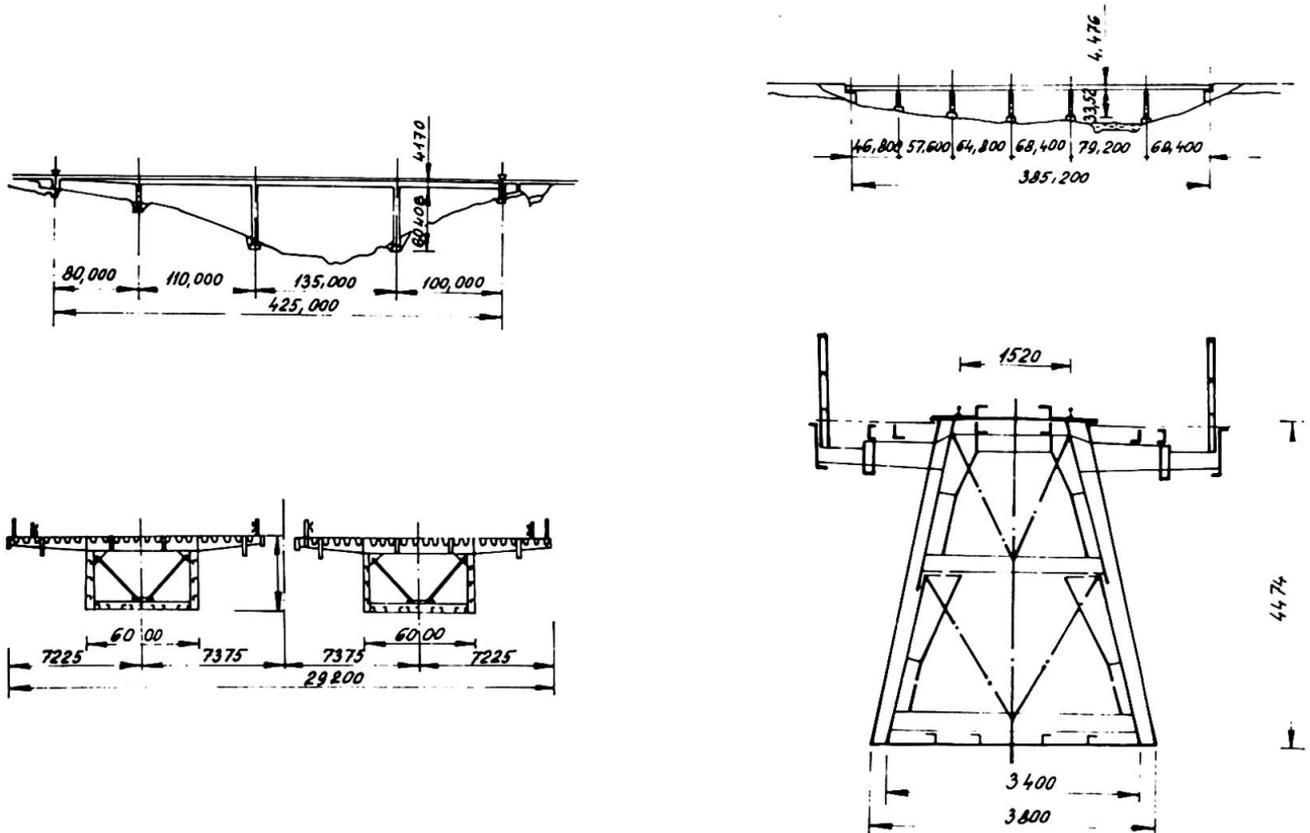

Fig.1: The Velke Mezirici motorway bridge
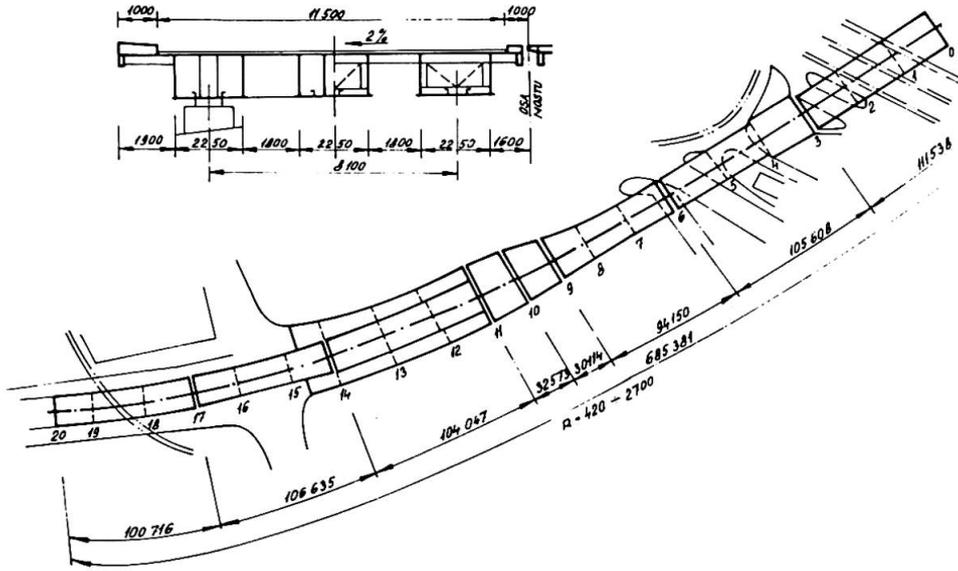
Fig.2: The railway bridge at Ivancice

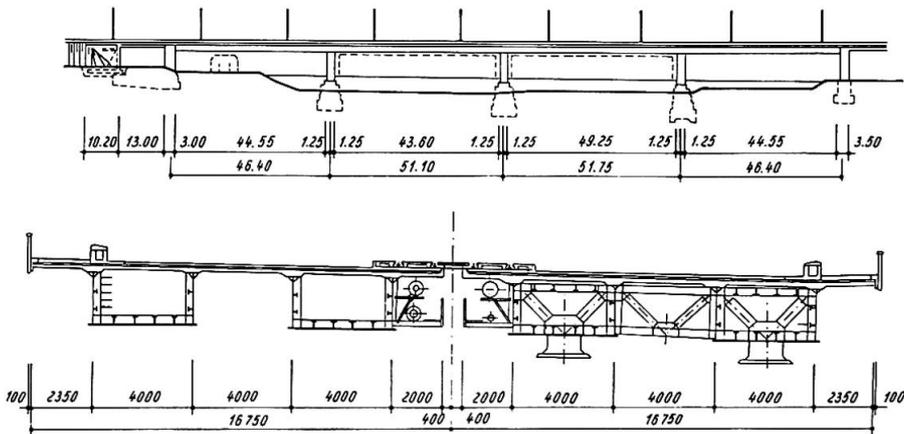Fig.3: The fly-over crossing the railway station Prague Centre

Fig.4: Barricade fighters Bridge in Prague

Table 1: The results of the statistical evaluation.

Bridge	Element	Dimension l (mm) $b+$ (mm)	Number of Measurements	R (MPa)	The boundaries of 95% of all measurements Absolute values (mm)		Nondimensional parameters y_0/l, resp. w_0/b		$> \dfrac{l}{500}$ $> \dfrac{b}{250}$
Velké Meziříčí	*Longitudinal stiffeners*	2500	130	290	−13.7	17.5	$-\dfrac{1}{182}$	$\dfrac{1}{143}$	76.9%
Ivančice		1800	42	290	−4.3	5.9	$-\dfrac{1}{419}$	$\dfrac{1}{305}$	11.9%
Prague-Centre		1900	60	210	−2.3	7.9	$-\dfrac{1}{826}$	$\dfrac{1}{241}$	21.7%
Barricade Fighters Prague		2200	216	300	−2.1	5.5	$-\dfrac{1}{1048}$	$\dfrac{1}{400}$	5.1%
Velké Meziříčí	*Partial flange panels*	600.12	312	290	−2.9	5.3	$-\dfrac{1}{207}$	$\dfrac{1}{113}$	19.9%
		600.14	270		−5.3	5.5	$-\dfrac{1}{113}$	$\dfrac{1}{109}$	21.9%
		600.20	299	290	−4.3	5.2	$-\dfrac{1}{140}$	$\dfrac{1}{115}$	20.1%
		600.32	280		−3.9	4.1	$-\dfrac{1}{154}$	$\dfrac{1}{150}$	14.6%
Ivančice		800.16	96	290	−2.5	2.1	$-\dfrac{1}{320}$	$\dfrac{1}{381}$	1.0%
Prague-Centre		750.14	37	210	−0.4	5.9	$-\dfrac{1}{1875}$	$\dfrac{1}{227}$	45.9%
		750.20	53		−0.6	3.5	$-\dfrac{1}{1250}$	$\dfrac{1}{214}$	7.5%
Barricade Fighters Prague		700.25	71		−2.4	2.7	$-\dfrac{1}{292}$	$\dfrac{1}{259}$	2.8%
		700.30	39		−2.9	3.1	$-\dfrac{1}{241}$	$\dfrac{1}{226}$	2.6%
		800.25	64	300	−3.8	4.2	$-\dfrac{1}{211}$	$\dfrac{1}{190}$	12.5%
		800.30	37		−4.2	5.2	$-\dfrac{1}{190}$	$\dfrac{1}{154}$	24.3%
		1000.25	36		−2.1	6.8	$-\dfrac{1}{476}$	$\dfrac{1}{147}$	58.3%
		1000.30	23		−2.1	5.2	$-\dfrac{1}{476}$	$\dfrac{1}{192}$	13.0%

Table 2: The impact of the imperfections on a reduction of the ultimate strength.

Bridge	Measured imperfections				Normative tolerances				200% of normative tolerances			
	m_{1N}	m_{2N}	$m_N = m_{1N} \cdot m_{2N}$	reduction%	m_{1N}	m_{2N}	$m_N = m_{1N} \cdot m_{2N}$	reduction%	m_{1N}	m_{2N}	$m_N = m_{1N} \cdot m_{2N}$	reduction%
Velké Meziříčí	0.9712	0.9128	0.8865	11.35	0.9947	0.9091	0.9043	9.57	0.9854	0.9106	0.8973	10.27
Ivančice	0.9923	0.9016	0.8947	10.53	0.9962	0.9010	0.8975	10.25	0.9902	0.9020	0.8932	10.68
Prague-Centre	0.8691	0.8782	0.7632	23.68	0.9368	0.8622	0.8077	19.23	0.8737	0.8771	0.7663	23.37
Barricade Fighters, Prague	0.9809	0.9759	0.9572	4.28	0.9861	0.9752	0.9616	3.84	0.9652	0.9778	0.9439	5.61