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Validation of the dynamic amplification factor in case of historic railway steel bridges with short and medium spans

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Abstract

One of the significant parameters in design as well as fatigue assessment of railway bridges is the dynamic factor. The dynamic factor, also called dynamic amplification factor (DAF), must be applied to the static load model in order to take account of dynamic magnification of stresses and vibration effects in the bridge. The dynamic factor which actually enhances the static load effects depends on many parameters that are difficult to take into account with reasonable accuracy. The maximum bridge-span, train speed, self-weight, expansion joints if any is placed in bridge, the type of bridge supports and finally soil–structure interaction are among these parameters. This paper studies the variations of the analytical and experimental observations on steel railway bridge dynamics. For this purpose the measured stresses due to passing a locomotive through a historical steel railway bridge in Germany are compared with the calculated stresses contemplating the dynamic factor proposed by EN1991-2 [1] applied to the static load model of the same locomotive.

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1. Introduction

There are lots of historic railway steel bridges in the German Railway Network which are still (more than 120 years) in service. These bridges have been long subjected to daily traffic including heavy trains. In order to get a

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better understanding of structural behavior of the bridges as well as the dynamic interaction between the bridges and vehicles, it is necessary to consider the dynamic factor. The theoretical value of the dynamic factor defined in EN1991-2 depends directly only on a single variable, i.e., the determinant length of the bridge. It is very clear that the dynamic factor is also indirectly affected by the shape of the influence lines of bridge members. In other words, some other significant parameters affecting the dynamic factor, including dynamic characteristics of the bridge (e.g., bridge natural frequencies, bridge damping effects, etc.) and train (e.g., train mass and center of gravity, train speed, resonance effects due to high speed trains, etc.) are being ignored in the Eurocode 1 [1]. As a result, the calculated values of the dynamic factor seem to be conservative and consequently result in dynamic effects that might not necessarily correspond to static effects.

On the other hand, since the fatigue assessment has not been carried out at the time of the design of these historic bridges, the German Railways (Deutsche Bahn) has decided to provide a reliable database of stress values by measuring the stresses in vital members (in terms of fatigue) of one of the most fatigue critical bridges in order to evaluate its remaining fatigue life. The database has been used in this paper to investigate the level of conservatism of the calculated dynamic factor and also to verify whether this level of conservatism is acceptable or not.

2. Case Study

A single span railway (single-track) steel truss bridge with a span of 20 *m* along Nürnberg-Schirnding route, lying in a curve of 641 *m* radius, is investigated to evaluate the variations of stresses due to passing a locomotive over the bridge with different speeds. The bridge is made up of two 1.92 *m* high steel trusses as main load carrying system and two cross steel trusses as secondary system. The distance between the axes of the main trusses is 1.7 *m*.

The speed limit for freight trains is 110 *km/h* and for tilting passenger trains 140 *km/h*. The bridge is since 1899 in service and has been recalculated in 1957.

2.1. Measurement set-up

The objective of strain measurement of critical members in any bridge is to get reliable information on the real structural behavior due to dynamic loading in order to decrease model uncertainties associated with the static calculations in the design process as well as bridge fatigue assessment.

The diagonal members as well as bottom chords near the supports in both trusses have been identified as fatigue critical members of the studied bridge. Four strain gauges were positioned at each diagonal member and one sensor at lower chords near each support of the bridge. In addition, three other strain gauges are positioned in the middle of the bridge.

This point must be noted that the live load strains (stresses) near the gusset plates were measured to determine the stiffness of connections as well as secondary bending moments in connections. The locations of the sensors are shown in Fig. 1 and 2 [2].

Fig. 1. Pegnitz railway bridge; locations of the strain gauges.

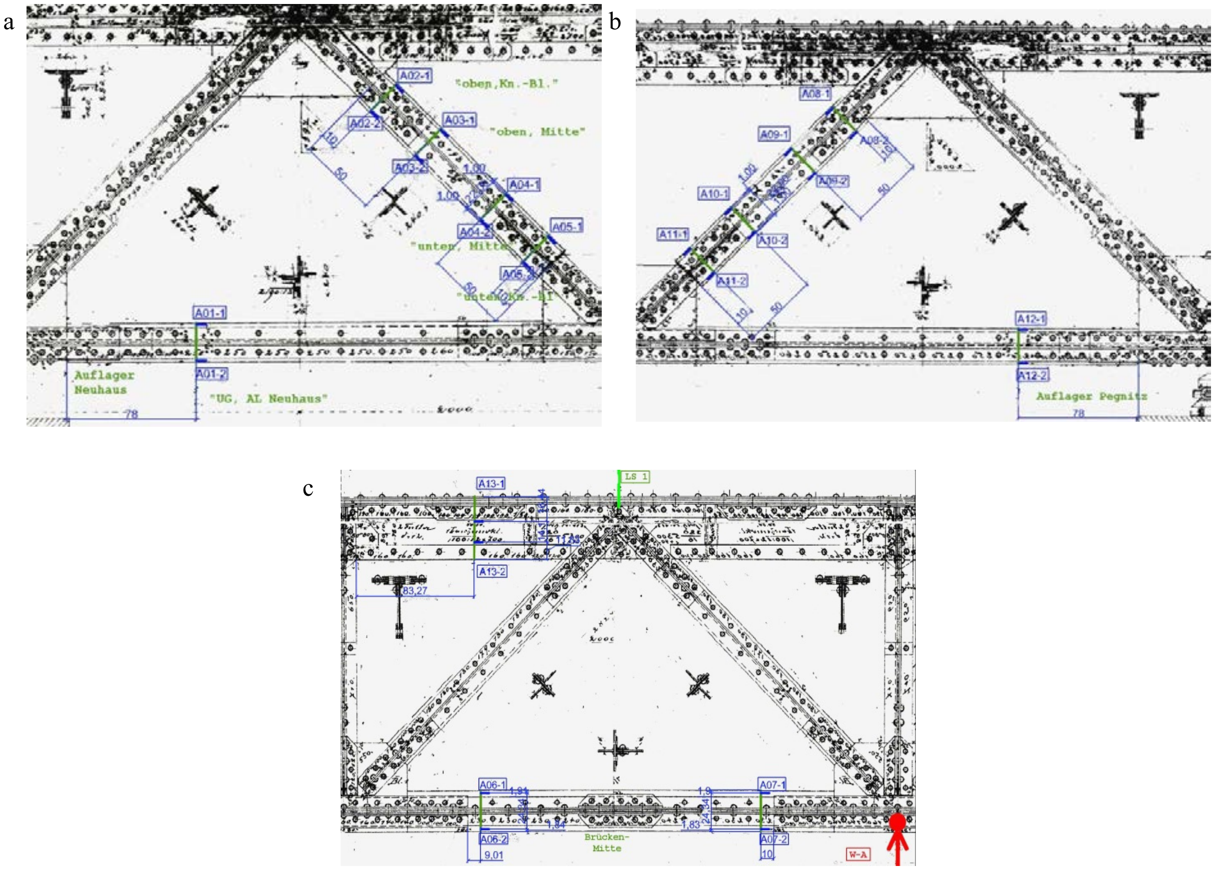

Fig. 2. Positions of strain gauges in detail (a) near the Neuhaus support; (b) near the Pegnitz support; (c) in the middle of the bridge.

2.2. Vehicle

The live load strains were measured due to passing the locomotive 218. The dimensions and technical data of the locomotive 218 are as follows [2]:

Manufacturer	Krupp, Henschel, Krauss-Maffei, MaK
Years of manufacture	1968; 1971; 1979
Axle	B'B'
Gauge:	1435 mm (normal gauge)
Length:	16.400 mm
Distance between bogie pivots	8.600 mm
pivot bogie axle base:	2.800 mm
Service weight:	80.0 t
Axle load:	20.0 t

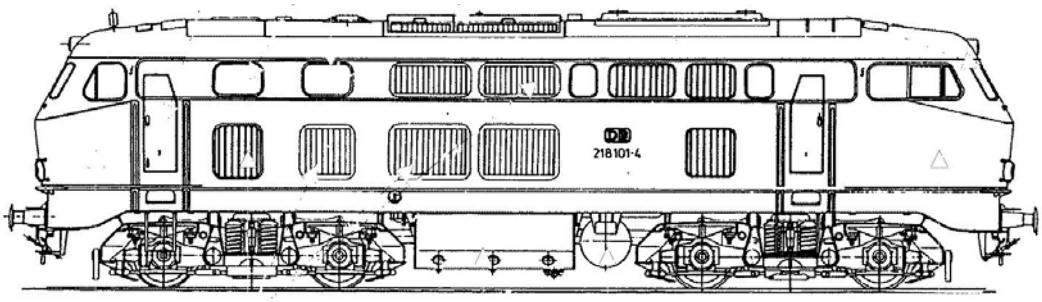

Fig. 3. Locomotive 218.

2.3. Measurement results

In this section, measured stresses due to passing the locomotive 218 over the bridge at different speeds are presented [2]. These results are later used to derive the relevant dynamic factors, contemplating the speed of the locomotive.

The locomotive 218 crossed the bridge at speeds of 50 *km/h*, 80 *km/h* and 110 *km/h.* In order to avoid any considerable error while measuring the strains (stresses), the locomotive crossed the bridge at each speed thrice. The mean values of the induced stresses at each speed are taken to derive the dynamic factors.

The measured data for speeds of 50 *km/h* as well as 80 *km/h* are given in Table 1 and for speed of 110 *km/h* are given in Table 2.

Table 1. Measured stresses induced by passage of locomotive 218; v = 50 *km/h* and v = 80 *km/h*.

Measured section	v = 50 *km/h*				v = 80 *km/h*			
	σ_1(MPa)	σ_2(MPa)	σ_3(MPa)	$\bar{\sigma}$(MPa)	σ_1(MPa)	σ_2(MPa)	σ_3(MPa)	$\bar{\sigma}$(MPa)
01-1	32.93	32.76	32.88	32.86	32.36	32.74	33.25	32.79
02-1	8.52	8.28	8.45	8.42	8.46	7.99	8.19	8.21
03-1	22.93	22.62	22.78	22.78	22.38	22.26	22.65	22.43
04-1	32.25	32.55	32.03	32.28	31.32	31.23	30.93	31.16
05-1	22.13	22.35	22.08	22.19	21.20	20.66	21.08	20.98
06-1	29.18	28.64	29.20	29.00	29.20	29.23	28.84	29.09
07-1	30.59	30.20	30.21	30.34	31.74	31.90	31.57	31.74
08-1	8.73	8.84	8.66	8.74	8.38	8.24	8.29	8.30
09-1	24.86	24.66	24.38	24.63	23.62	23.36	22.98	23.32
10-1	32.37	32.35	32.39	32.37	32.20	32.37	31.57	32.05
11-1	20.96	21.07	20.95	20.99	21.75	21.39	21.37	21.50
12-1	35.65	36.05	36.00	35.90	37.61	37.62	38.10	37.77
13-1	20.55	20.68	20.67	20.63	19.73	19.69	19.67	19.70
01-2	18.54	19.51	17.22	18.42	20.91	19.72	22.44	21.03
02-2	24.76	24.54	24.53	24.61	22.95	23.19	23.32	23.15
03-2	39.58	39.43	39.68	39.56	38.05	37.85	37.97	37.96
04-2	29.23	29.42	29.07	29.24	28.20	27.86	28.04	28.03
05-2	10.03	9.89	9.71	9.87	9.42	9.41	9.33	9.39
06-2	34.35	34.20	34.23	34.26	36.50	36.34	36.15	36.33
07-2	33.98	34.12	34.17	34.09	34.14	34.26	33.97	34.13
08-2	18.05	18.04	17.95	18.01	18.11	17.89	17.82	17.94
09-2	40.51	40.20	39.99	40.23	40.80	40.71	40.53	40.68
10-2	30.29	30.22	30.13	30.22	30.66	30.38	30.36	30.47
11-2	11.54	11.52	11.25	11.44	11.33	11.44	11.20	11.32
12-2	22.29	22.23	22.42	22.31	23.45	23.84	24.88	24.06
13-2	18.17	18.10	18.34	18.20	17.14	17.28	16.89	17.10

Table 2. Measured stresses induced by passage of locomotive 218; v=110 *km/h*.

Measured section	σ_1(MPa)	σ_2(MPa)	σ_3(MPa)	$\bar{\sigma}$(MPa)	Measured section	σ_1(MPa)	σ_2(MPa)	σ_3(MPa)	$\bar{\sigma}$(MPa)
01-1	35.37	35.61	35.00	35.33	01-2	24.45	23.60	22.81	23.62
02-1	7.71	7.33	7.67	7.57	02-2	25.09	25.60	25.41	25.37
03-1	22.24	22.49	22.00	22.24	03-2	40.12	41.34	40.17	40.55
04-1	32.49	31.79	31.78	32.02	04-2	29.00	28.31	29.08	28.80
05-1	22.85	24.49	22.85	23.40	05-2	10.04	9.71	10.32	10.02
06-1	30.39	30.28	31.06	30.57	06-2	35.93	36.58	36.00	36.17
07-1	32.17	32.41	32.68	32.42	07-2	35.64	36.30	36.28	36.07
08-1	8.23	8.60	8.57	8.47	08-2	18.59	18.36	18.90	18.62
09-1	23.53	23.35	23.74	23.54	09-2	41.79	41.36	42.31	41.82
10-1	31.93	31.43	31.56	31.64	10-2	30.88	29.82	30.93	30.54
11-1	22.94	22.49	22.82	22.75	11-2	10.84	11.11	10.91	10.95
12-1	37.99	38.26	38.37	38.21	12-2	24.17	24.27	24.28	24.24
13-1	19.73	19.87	20.03	19.88	13-2	17.71	17.80	17.79	17.77

2.4. Static calculation

The bridge has been statically calculated, using the finite element computer program Sofistik. The locomotive 218 is in the static model represented by its moving axle forces. Thus, no interactions between locomotive – bridge and no track irregularities are in the static analysis regarded. The calculated stresses are then calibrated with measured data in order to evaluate the dynamic factors with respect to the speed of the locomotive.

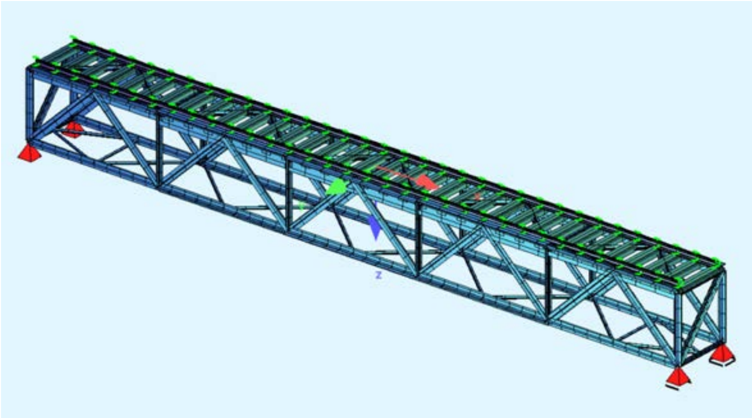

Fig. 4. Isometric view of computer model of the bridge.

- The static calculated stresses in the same (measured sections) sections are listed in the Table 3.

Table 3. Static calculated stresses.

Studied section	σ(MPa)
01-1	33.26
02-1	8.21
03-1	22.15
04-1	31.47
05-1	21.18
06-1	29.23
07-1	30.33
08-1	8.88
09-1	24.30
10-1	31.70
11-1	21.07
12-1	35.75
13-1	20.19
01-2	21.31
02-2	24.09
03-2	38.63
04-2	28.46
05-2	9.70
06-2	34.44
07-2	34.05
08-2	17.95
09-2	39.38
10-2	30.07
11-2	11.83
12-2	23.72
13-2	17.62

- Calculation of dynamic factor

According to EN1991-2 the dynamic factor can be calculated as follows:

$$\phi_2 = \frac{1.44}{\sqrt{L_\phi} - 0.2} + 0.82$$

$$\phi_2 = \frac{1.44}{\sqrt{20} - 0.2} + 0.82 = 1.16$$

2.5. Verification of the dynamic factor

In this section the measured stresses are being compared with the static calculated stresses in order to get the real dynamic factor. Table 4 shows the real dynamic factors which are actually the proportion of the experimentally determined stresses to the static calculated ones in each section.

Table 4. Measured stresses, static calculated stresses and the derived dynamic factors.

Section	V=50 *km/h*			V=80 *km/h*			V=110 *km/h*		
	$\bar{\sigma}_{dyn}$(MPa)	σ_{stat}(MPa)	$\emptyset_2$	$\bar{\sigma}_{dyn}$(MPa)	σ_{stat}(MPa)	$\emptyset_2$	$\bar{\sigma}_{dyn}$(MPa)	σ_{stat}(MPa)	$\emptyset_2$
01-1	32.86	33.26	0.99	32.79	33.26	0.99	35.33	33.26	1.06
02-1	8.42	8.21	1.03	8.21	8.21	1.00	7.57	8.21	0.92
03-1	22.78	22.15	1.03	22.43	22.15	1.01	22.24	22.15	1.00
04-1	32.28	31.47	1.03	31.16	31.47	0.99	32.02	31.47	1.02
05-1	22.19	21.18	1.05	20.98	21.18	0.99	23.40	21.18	1.10
06-1	29.00	29.23	0.99	29.09	29.23	1.00	30.57	29.23	1.05
07-1	30.34	30.33	1.00	31.74	30.33	1.05	32.42	30.33	1.07
08-1	8.74	8.88	0.98	8.30	8.88	0.94	8.47	8.88	0.95
09-1	24.63	24.30	1.01	23.32	24.30	0.96	23.54	24.30	0.97
10-1	32.37	31.70	1.02	32.05	31.70	1.01	31.64	31.70	1.00
11-1	20.99	21.07	1.00	21.50	21.07	1.02	22.75	21.07	1.08
12-1	35.90	35.75	1.00	37.77	35.75	1.06	38.21	35.75	1.07
13-1	20.63	20.19	1.02	19.70	20.19	0.98	19.88	20.19	0.98
01-2	18.42	21.31	0.86	21.03	21.31	0.99	23.62	21.31	1.11
02-2	24.61	24.09	1.02	23.15	24.09	0.96	25.37	24.09	1.05
03-2	39.56	38.63	1.02	37.96	38.63	0.98	40.55	38.63	1.05
04-2	29.24	28.46	1.03	28.03	28.46	0.98	28.80	28.46	1.01
05-2	9.87	9.70	1.02	9.39	9.70	0.97	10.02	9.70	1.03
06-2	34.26	34.44	0.99	36.33	34.44	1.05	36.17	34.44	1.05
07-2	34.09	34.05	1.00	34.13	34.05	1.00	36.07	34.05	1.06
08-2	18.01	17.95	1.00	17.94	17.95	1.00	18.62	17.95	1.04
09-2	40.23	39.38	1.02	40.68	39.38	1.03	41.82	39.38	1.06
10-2	30.22	30.07	1.00	30.47	30.07	1.01	30.54	30.07	1.02
11-2	11.44	11.83	0.97	11.32	11.83	0.96	10.95	11.83	0.93
12-2	22.31	23.72	0.94	24.06	23.72	1.01	24.24	23.72	1.02
13-2	18.20	17.62	1.03	17.10	17.62	0.97	17.77	17.62	1.01

The differences between the derived values of dynamic factors from the experimentally determined stresses (given in Table 4) and the Eurocode proposed dynamic factor lie in simplifications that come from making assumptions on the formula in Eurocode. As mentioned before, the determinant length of the bridge is the only parameter which has been considered in the Eurocode proposed formula for dynamic factor. It doesn't even take the vehicle speed into account. In addition, dynamic characteristics of the bridge itself as well as specifications of the locomotive (e.g. its mass and center of gravity, etc.) have been ignored in this formula.

3. Conclusion and suggestion

The main conclusion that is drawn from the results presented in previous sections (with respect to the comparison between the static calculated and experimental measured stresses) is that the calculated dynamic factor proposed by Eurocode keeps the results conservatively on the safe side. This level of conservatism is acceptable for design of new short span bridges. However in case of fatigue assessment of old bridges, it may cause misleading results.

It would be more reasonable to focus on dynamic interaction of train and bridge in order to get more reliable results for fatigue assessment. Therefore dynamic calculation of the bridge is the further step which has to be taken for studying the fatigue behavior as well as determining the stress history of fatigue critical members of the bridge.

References

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