International Scientific Conference CIBv - Civil Engineering and Building Services
5th-6th November 2020

Fatigue assessment of welded steel highway bridges in accordance with the European Standards

Radu BĂNCILĂ, Edward PETZEK, Anamaria FEIER, Dorin RADU

1. INTRODUCTION

The development of the highway network in our country, leads to the need to build a large number of bridges, from small spans to important bridges with large spans.
In the present conditions, of the significant increase in road traffic, both in frequency and axle load, fatigue becomes the determining factor in the design of bridges.
The paper presents an analysis of the traffic on the A1 highway, its systematization, and the effect on the existing bridge structures, in accordance with the European Standards SR-EN-1993-1-9 and SR-EN-1991-2-2000.
The determining factor in the bridge design, becomes the phenomenon of fatigue.
When the Romanian Standard - STAS 1844/1975 appeared: "Steel highway bridges-design requirements", due to the relatively low traffic, the fatigue verification of the highway bridges was not necessary.

The dramatic growth in recent decades, in frequency and tonnage, along with the emergence of major defects in some relatively new bridges, designed in the 1960's, have led to a reconsideration of the above statement.
The European Standard EUROCODE have given special importance to the problem of fatigue, in terms of ensuring a lifespan of 100 years for the designed structures, and a probabilistic safety concept.

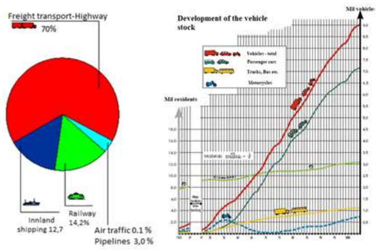
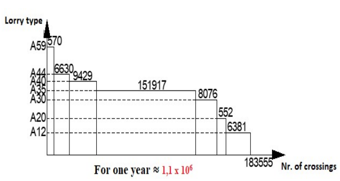


Fig.1. The significant increase in road traffic in Germany in recent decades

2. TRAFFIC CLASSIFICATION

For a correct classification of the real traffic, the Regional Directorate of Roads and Bridges (DRDP Timișoara) was requested to present , the type and number of trucks entering the country, at the crossing point of the Nădlac border.
It is mentioned that each truck is weighed so that the structure of heavy truck traffic can be determined exactly. For the systematization of the traffic, a weighted average of the vehicles of close weights was performed (both in terms of tonnage and in terms of distance between the axles). Finally, seven standard vehicles were established, covering the current traffic, called conventionally A12, A20, A30, A35, A40, A44 and A59.



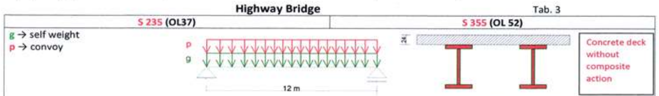
Nr. Crt.	Typified Lorry	Number of Crossings	Percent %	OBS	M_{max} [kN/m]	A30 (STAS)
1	A 59	570	0,31	≅ 92%	826	811 cu coeficient dinamic Ψ = 1,3
2	A 44	6630	3,61		598	
3	A 40	9429	5,14		498	
4	A 35	151917	82,76		487	
5	A 30	8076	4,40	≅ 8%	420	
6	A 20	552	0,30		392	
7	A 12	6381	3,48		240	
TOTAL		183555	100 %	100 %		

Fig.2. Histogram of the typified traffic (for two months) and overview of the typified lorries

3. CASE STUDY – ASSESSING THE IMPLICATIONS OF THE INCREASED TRAFFIC

To assess the impact of these vehicles resulting from the actual traffic on the bridge structure, a steel highway bridge with a span of L = 12m was chosen.
This bridge - considered as existing - was designed in accordance with the Romanian Standard STAS 1844/1975,with the allowable resistances method - MRA (valid at that time). The calculus can be followed in Table 3. Two steel grades OL 37 (S235) and OL52 (S355) were considered.
The calculation is performed in parallel with the method of allowable resistances (MRA) and at limit states (MSL), corresponding to the calculation method of the European standard.
According to present fatigue concept, the relevant parameter is the stress range Δσ. For the simply supported beam, this is the stress produced by the convoy.

Highway Bridge — Tab. 3



Loads

- g_1 = the weight of the reinforced concrete slab on a beam → $g_1 = (2+3)\cdot 0,24\cdot 25 = 30\ \frac{kN}{m}$
- g_2 = parapets, waterproofing, separating elements → $g_2 = 3,6\ \frac{kN}{m}$
- g_3 = self-weight girder → $g_3 \cong 1,0\ \frac{kN}{m}$
- TOTAL $g \cong 35\ \frac{kN}{m}$
- Standard convoy A 30 → $p = 35\frac{kN}{m}\cdot 1,3 = 45\frac{kN}{m}$
- Dynamic amplification factor $\Psi = 1 + \frac{15}{37,5 \cdot L} = 1,3$

Load-bearing capacity

CROSS SECTION: I_z = 560.300 cm⁴, W_z = 9.110 cm³

$M^g_{max} = \frac{35\cdot 12^2}{8} = 630\ kNm \rightarrow \sigma_g = \frac{630\cdot 10^2}{9110} = 6,91\ \frac{kN}{cm^2}$

$M^p_{max} = \frac{45\cdot 12^2}{8} = 820\ kNm \rightarrow \sigma_p = \frac{820\cdot 10^2}{9110} = 9\ \frac{kN}{cm^2}$

TOTAL =15,91 kN/cm²

Obs. With MRA $\sigma_a = 24/(1,5) = 16\ kN/cm^2$
DEFLECTION with M_{max} = 1450 kNm

CROSS SECTION: I_z = 292.700 cm⁴, W_z = 6.290 cm³

$M^g_{max} = \frac{35\cdot 12^2}{8} = 630\ kNm \rightarrow \sigma_g = \frac{630\cdot 10^2}{6290} = 10\ \frac{kN}{cm^2}$

$M^p_{max} = \frac{45\cdot 12^2}{8} = 820\ kNm \rightarrow \sigma_p = \frac{820\cdot 10^2}{6290} = 13\ \frac{kN}{cm^2}$

TOTAL =23 kN/cm²

Obs. With MRA $\sigma_a = 36/1,5 = 24\ kN/cm^2$
DEFLECTION with M_{max} = 1450 kNm

The calculation is performed in parallel with the method of allowable resistances (MRA) and the method at limit states (MSL), corresponding to the calculation method of the European standard. According to present fatigue concept, the relevant parameter is the stress range Δσ. For the simply supported beam, this is the stress produced by the convoy.

$$f_{max} = \frac{5\cdot 1450\cdot 10^2\cdot 12\cdot 10^4}{48\cdot 21000\cdot 560300} = 1,83cm < \frac{1200}{300} = 4cm$$

$$f_{max} = \frac{5\cdot 1450\cdot 10^2\cdot 12\cdot 10^4}{48\cdot 21000\cdot 292700} = 3,4cm < \frac{1200}{300} = 4cm$$

Obs. 1. M^p_{max} (with convoy A30 on the inluence line → 811 kNm)
2. p/g ≅ 1,3

FATIGUE DESIGN – SR-EN1993-1-9-2006

MRA	EC3	MRA	EC3
• g = 35kN/m • p = 35 · 1,3 = 45 kN/m (1,3 dynamic amplification factor) • $M^g_{max} = \frac{35\cdot 12^2}{8} = 630\ kNm$ • $M^p_{max} = \frac{45\cdot 12^2}{8} = 820\ kNm$ $\rightarrow \sigma_g \cong 7\frac{kN}{cm^2}$ $\rightarrow \sigma_p = 9\frac{kN}{cm^2}$ Total 16 kN/cm² = σ_a	Obs. Dynamic load amplification is included! x 1,35 (γ_g) x 1,50 (γ_p) 7 x 1,35 = 9,45 kN/cm² 9 x 1,50 = 13,50 kN/cm² TOTAL 23 < 23,5 kN/cm² (f_{yk})	• g = 35kN/m • p = 35 · 1,3 = 45 kN/m $M^g_{max} = \frac{35\cdot 12^2}{8} = 630\ kNm$ • $M^p_{max} = \frac{45\cdot 12^2}{8} = 820\ kNm$ $\rightarrow \sigma_g \cong 10\frac{kN}{cm^2}$ $\rightarrow \sigma_p = 13\frac{kN}{cm^2}$ TOTAL 23 < σ_a = 24 kN/cm²	Obs. Dynamic load amplification is included! x 1,35 (γ_g) x 1,50 (γ_p) 10 x 1,35 = 13,5 kN/cm² 13 x 1,50 = 19,5 kN/cm² TOTAL 33 < 35,5 kN/cm² (f_{yk})
	Oboseală $\gamma_g = 1,0$; $\gamma_p = 1,0$		Oboseală $\gamma_g = 1,0$; $\gamma_p = 1,0$
Δσ = 9 kN/cm²		Δσ = 13 kN/cm²	

Note that the stress range has the same value in MRA as in MSL !

- Constructive details (EC3-1-9)
- Damage tolerant consequences $\gamma_{Mf} = 1,15$

⇨ Constructive detail **80** / 1,15 = 70 = 7 kN/cm²
⇨ Constructive detail **71** / 1,15 = 62 = 6,2 kN/cm²
⇨ Constructive detail **100** / 1,15 = 87 = 8,7 kN/cm²
⇨ Constructive detail **112** / 1,15 = 97 = 9,7 kN/cm²
⇨ Constructive detail **125** / 1,15 = 109 = 10,9 kN/cm²

⇨ Fatigue condition not fulfilled ; min. constructive detail 100 | **⇨ Fatigue condition not fulfilled ; min. constructive detail 125**

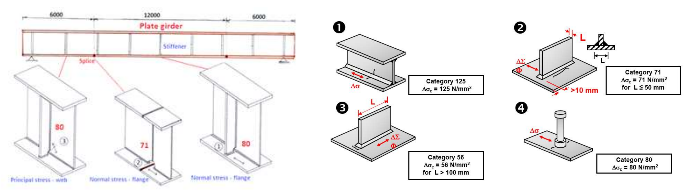
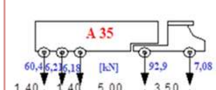


Fig.3. Notch cases – depending on constructive details

Each truck is considered to cross the bridge in the absence of other vehicles, causing damage. The constructive detail 80 (stiffener on the web in the middle of the span) was chosen.
The Palmgren – Langer rule of the cumulative damage was used. Successively the following steps are fulfilled:

- Passing the load model (truck) over the influence line; ⇨ Mmax for the section in the middle of the beam using the line of influence;
- Calculation of the stress range Δσ (produced by the convoy) for each vehicle, respectively A59, A44, A40, A35, A30, A20 and A12;
- calculation of the number of heavy lorries in one year;
- Determine from the corresponding Wöhler curve Δσ-N or Δτ-N, the number of cycles leading to fatigue resistance;
- Calculation of the total damage D

For usual cases, such as for simply supported road bridges, the stress histogram can be easily obtained with hand calculations.



M1 =7,08 x 1,3 +9,29 x 3 + 6,18 x 0,5 = 401,6 kNm
M2 =9,29 x 0,8 +6,18 x 3 + 6,21 x 2,3 + 6,04 x 1,6 = 500 kNm
$\Delta\sigma = [50\cdot 10]^2/9110 = 5,48\ kN/cm^2$ → Wöhler curve with m=3
$N_R = (6,96/5,48)^3\cdot 2\cdot 10^6 = 4,09\cdot 10^6$
$\boldsymbol{n = 151917\cdot 6 = 911502\ crossings/year \approx 0,9\cdot 10^6}$
Total damage in one year: $\sum n/N = 0,9/4,09\cdot(10^6)/(10^6) = \mathbf{0,22}$

In the same way the damage produced by each conventional vehicle was calculated. Finally the cumulative damage produced by the real traffic in one year, is:
$S = \sum n_i/N_i$ = 0,0005 + 0,005 + 0,22 + 0,0013 + 0,02 + 0,004 = 0,261

Present traffic in NĂDLAC 2019 (n ≅ 1,1 x 10⁶)

Nr.	Convoy	Stress range Δσ [kN/cm²]	Truck percent	Damage / year	Obs.
1.	A12	-	3,48 %	-	
2.	A20	4,3	0,3 %	0,0005	
3.	A30	4,61	4,4 %	0,005	
4.	A35	5,34	82,76 %	0,22	
5.	A40	5,46	5,14 %	0,0013	
6.	A44	6,56	3,61 %	0,02	
7.	A59	9,07	0,31 %	0,004	
TOTAL			100 %	0,261	

4. CONCLUSIONS

The total annual damage (degradation) is equal to Σn/N = 0.261. It results that in the current traffic conditions (in the near future certainly the loads and traffic will increase), in 4 years the life of the structure is reached. The bridges will not collapse suddenly; rigorous and regular observations will be required with monitoring of sensitive details.
Dd = 1,0 when n = N
Dd < 1,0 when n < N
If 0.8 < Dd < 1 inspection is recommended (based on VT – visual testing)
If Dd ≥ 1 immediately inspection with sur place conclusions
The important traffic increase in frequency and in weight on the axle, leads to the reconsideration of the bridge structures, especially those situated on highways, but also of those located on national roads. The decisive aspect becomes the fatigue behaviour of the structure.
The chosen calculation example is a bridge with a modest span L = 12m, but the conclusions are relevant, they can be even more severe at large spans!
As pointed out above, this doesn't mean the structure will collapse immediately, but the possibility of degradations (cracks, deformations), which must be carefully monitored.