Testing the Properties of Structural Cast Steel (Flußstahl) in Old Railway Bridges

Janusz HOŁOWATY
Assistant Professor
West Pomeranian Univ. of Technology in Szczecin, PL
jah@wp.pl

Janusz Hołowaty, born 1956, graduated in civil engineering from the Technical Univ. of Szczecin, Poland (now WPUT). PhD from Wrocław Univ. of Technology, Poland in 1995. His area of research is bridge testing and design.

Bernard WICHTOWSKI
Professor
West Pomeranian Univ. of Technology in Szczecin, PL
marek.wichtowski@zut.edu.pl

Bernard Wichtowski, born 1937, received his civil engineering degree from the Technical Univ. of Szczecin (now WPUT). PhD in 1981 and habilitation thesis in 2004. His area of research is the fatigue strength and durability of steel structures.

Summary

The long-term use of steel bridges leads to changes in the mechanical properties of their structural steels. This issue is demonstrated in a study of cast steels from four railway truss bridges built in 1875 on one of the oldest railway lines in Poland. The tests for each bridge involved: an analysis of the chemical composition, determination of hardness and toughness, along with yield strength and ultimate strength. These tests made it possible to calculate the degree of degradation and current mechanical properties of the steels.

Keywords: old railway bridge, historic bridge, cast steel, ageing of steel, durability.

1. Truss bridges

The three-span riveted bridges are marked A, B and C in the paper. The structural plans for the bridges are comparable to those shown in Fig. 1, differing only in minor details, and with span lengths of between 33,80 m and 35,90 m. Historically, the entire railway line had a double track. In 1945, one track was dismantled. On the second track only one span remained near the bridge B. The span is marked as bridge D and an analysis of the steel taken from a vertical truss member and a floor stringer is presented in the paper. The upper chords of the truss girders have a hat section and the lower chords are two panels connected by battens and stiffened by vertical members. The cross beams and stingers are rolled steel beams.

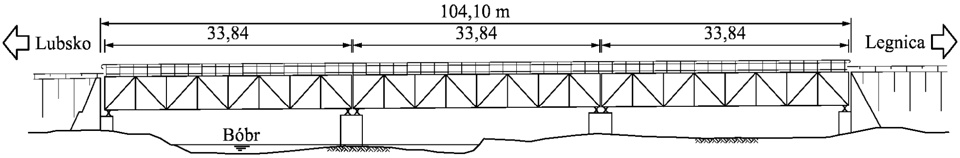

Fig. 1: Side view of bridge A over the River Bobr

2. Chemistry and mechanical properties of the steel

A spectrometric chemical analysis of 21 steel samples was performed. In Table 1, the chemical analysis of the steel is shown for a eight basic alloy elements from the twenty elements obtained. Comparison of the chemical composition of the steels in all four bridges results in the conclusion that the old railway truss bridges were built from cast steel (Flußstahl).

Steel tension tests (ISO 6892-1) were carried out on 18 samples (naturally aged) from bridges A, B, C, and on 7 samples from bridge D: 5 samples were naturally aged (S) and 2 samples were normalised (N). For all tension curves there are clear yield strengths and a significant difference in the test results for yield strength R_e, tensile strength R_m and elongation A for the steel in bridge C compared to that in bridges A, B and D (Table 2).This is caused by the differing carbon content (Table 1). Bridge C was built from low-carbon steel and the other bridges from high-carbon steel.

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Table 1. Chemical composition of cast steel from the bridges and comparative steel, %

Type of steel	C	Mn	Si	P	S	Cu	Cr	Ni	Al
Bridge A	0,299	0,984	0,182	0,020	0,028	0,158	0,019	0,033	0,0002
Bridge B	0,233	0,685	0,178	0,036	0,041	0,140	0,019	0,045	0,0001
Bridge C	0,045	0,538	0	0,017	0,025	0,178	0,020	0,104	0,0001
Bridge D	0,258	0,591	0,192	0,026	0,043	0,241	0,025	0,136	0,0003
Wrought iron	0,02 ÷0,30	traces ÷0,33	0,01 ÷0,33	0,02 ÷0,46	0,01 ÷0,06	-	-	-	-
Cast steel	0,03 ÷0,35	0,04 ÷0,75	traces ÷0,18	0,004 ÷0,16	0,004 ÷0,12	0,11 ÷0,14	0,11 ÷0,14	0,03 ÷0,04	0,01 ÷0,02

Table 2. Results of static tension tests for aged (S) and normalised (N) steels

Bridge	Specimen size (mm)	Type of specimen	E [GPa]	$R_{e,av}$ [MPa]	$R_{e,L}$ [MPa]	R_m [MPa]	R_{mB} [MPa]	$R_{e,av}/R_m$	A [%]
A	Ø 7 L=35	S	175	322	296	560	534	0,57	29
B			192	319	300	510	489	0,62	30
C			197	253	244	376	372	0,67	37
D	Ø 8 L=40	S	195	343	335	549	498	0,62	29
		N	191	337	335	543	–	0,62	25

where $R_{e,av}$ – average yield strength, R_{mB} – ultimate strength according to Brinell hardness test, A – elongation at rupture

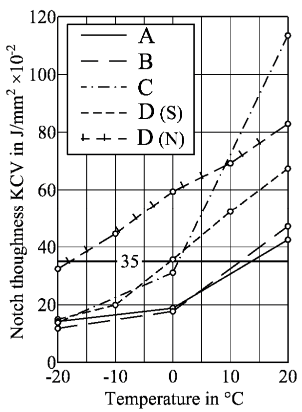

Fig. 2: Steel toughness for bridges A, B, C and D

Impact strength tests on the steels from the truss bridges were carried out with Charpy (KCV) notch specimens. Just as in the tension tests, the impact tests were performed for bridges A, B and C on 6 specimens at every temperature, naturally aged (S) and for bridge D on naturally aged specimens S and normalised specimens N. Results of the tests on specimens S and N allowed assessing the influence of the bridge service life period on the change of steel resistance for impact loads. Testing of the steel for fracture properties is shown in Figure 2. The steels in all four bridges exhibited very low fracture toughness at negative temperatures. The values at a temperature of 0°C are 50,6% and 102% of the required structural code fracture toughness of 35×10^{-2} J/mm^2. It should be noted that the fracture toughness of the steel from bridge D at delivery during construction of the bridge was sufficient and at a temperature of 0°C the toughness was KCV = $59,4\times10^{-2}$ J/mm^2. This fact proves the strong influence of the so-called ageing effect on steel ductility. The current transition temperature, describing the transition between ductile and brittle behaviour for the steel is 0°C.

3. Conclusion

All the bridges in the study were constructed from cast steel with different carbon contents. In bridge C, low-carbon cast steel was used (C = 0,045%) and in bridges A, B and D, high-carbon cast steel was used (C = 0,233%; 0,258% and 0,299%). This fact is a “revolution” with regard to opinions on the application of high-yield cast steel as far back as the 1870s. Stress-strain curves for the aged samples S and after normalisation N in bridge D showed that the results of static tensile tests cannot be considered a measure of the state of material degradation. For samples S and N, nearly identical results were obtained for R_e, R_m and A. However, very different results in the impact tests for samples S and N in bridge D were obtained.