Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 156 (2016) 180 – 185

Procedia Engineering

www.elsevier.com/locate/procedia

9th International Conference „Bridges in Danube Basin 2016“, BDB 2016

Mechanical properties of late-nineteenth-century bridge steel at low temperature

Paweł Grzegorz Kossakowski[a,*]

[a] *Kielce University of Technology, al. Tysiąclecia Państwa Polskiego 7, Kielce 25-314, Poland*

Abstract

The aim of the study was to determine the effect of low temperatures on the mechanical properties of the structural steel used in a late-nineteenth century bridge, which was in operation from 1885 until 2007. The investigations showed that the mechanical strength properties, i.e. yield strength and ultimate tensile strength, of the steel tested at T = – 30 ºC were much higher than those reported at room temperature, T = + 20 ºC. An increase was also observed in ductility, especially in the direction parallel to the rolling direction.

Peer-review under responsibility of the organizing committee of BDB 2016

Keywords: bridge; old bridge steel; temperature effect; mechanical properties of structural steels

Nomenclature

A_5	percentage extension [%]	ε	strain
E	Young's modulus [GPa]	σ	normal stress [MPa]
N	number of stress cycles	$\Delta\sigma$	normal stress range [MPa]
R_{eH}	upper yield strength [MPa]	$\Delta\tau$	shear stress range [MPa]
R_m	ultimate tensile strength [MPa]		
T	temperature [°C]		

* Corresponding author. Tel.: +48 41 34 24 175; fax: 48 41 34 24 784.
E-mail address: kossak@tu.kielce.pl

Peer-review under responsibility of the organizing committee of BDB 2016
doi:10.1016/j.proeng.2016.08.284

1. Introduction

During their long operation, buildings and other civil engineering structures are exposed to the negative impact of various factors, which cause the deterioration of the materials that they are made of. This leads to a decrease in the material strength parameters, the formation of defects, and consequently the failure of structural elements or even the entire superstructure. Old civil engineering structures, including metal bridges and viaducts, are particularly prone to damage. This is due to the use of materials such as cast iron and puddled or cast steel and the cyclical nature of loads associated with the movement of vehicles. Many of such objects are still in operation, in spite of the fact that their lifetime is over a hundred years. For such structures, fatigue is one of the fundamental problems [1, 2]. Corrosion is another unfavorable phenomena that increases the risk of failure of metal bridges [3]. Fatigue and corrosion are the fundamental factors that contribute to the formation of failure processes in metal bridge superstructures. Cracking is an example of such processes. Cracks occur when the fracture toughness of a material is exceeded. Cracks are observed both in old and in relatively new bridges [4]. As brittle fracture is extremely dangerous and needs to be prevented at early stages, extensive studies [5, 6] have been undertaken and relevant standards [7] have been introduced.

Cracking is strongly related to damage processes that take place in the material at the micro-scale level. In the case of structural steels used in the construction and bridge engineering, cracks are due to the presence of micro-defects in the form of microstructure discontinuities [8, 9]. The damage processes at the micro scale occur for static as well as cyclic loading of the bridge structural elements [10].The formation and growth of micro-defects observed during the deformation process is the most significant step leading to the material rupture and failure of the superstructure [11-15].

These phenomena are particularly important in the case of old bridges, which are used for longer than their expected lifetime. According to the requirements of the current EN 1990 standard [16], bridges should operate without failure for a period of 100 years. It is thus required that structures built between the nineteenth and early twentieth centuries be regularly inspected and monitored to reduce the risk of their failure. Research on the failure of various engineering structures, including bridges [17], as well as the failure mechanisms [10, 15, 18] is essential. State-of-the-art testing methods and equipment are used for bridge monitoring to detect damage [19].

The mechanical properties of structural steels used in the nineteenth and early twentieth century bridges need to be determined in order to assess the actual load-carrying capacity and safety of the structures. It is essential to take into consideration the environmental conditions in which bridges operate, especially the impact of temperature, because they greatly affect the material behavior. The influence of temperature on the mechanical properties of structural steel is taken into account, for instance, to predict its behavior under fire conditions [20-22]. It is also important to study changes in the mechanical properties of bridge steels at low temperatures. The yield strength, ultimate tensile strength and ductility determined at low temperatures, corresponding to real conditions under which a bridge operates, can be used to assess its load-capacity and safety. This paper discusses the effect of low temperature on the basic, standard mechanical properties of steel used in a late nineteenth century bridge.

2. Bridge structure and the experiments

The material under study was sampled from the structure of a railway bridge operating in Poland from 1885 to 2007. The bridge was used for 122 years, which was much longer than the 100 years assumed for such structures in the EN 1990 standard [16].

According to the EN 1991-2 [23] standard, it was assumed that the analyzed bridge with a service life of 122 years operated under standard traffic mix conditions with axles of ~ 22.5 t (225 kN). The corresponding number of stress cycles for the bridge and for the steel samples was about $N = 3 \cdot 10^6$. The estimated ranges of variability of normal stresses and shear stresses were $\Delta\sigma =$ 57 MPa and $\Delta\tau = 18$ MPa, respectively.

The bridge structure was composed of riveted steel girders with a total length of 16.6 m and transverse beams spaced at 1.9 m intervals. A side view of the railway bridge is shown in Fig. 1.