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The World's First Road Truss Welded Bridge in the Light of NDTs

Abstract: December 2018 marks the 90-th anniversary of the construction (1928) of the world's first road truss welded bridge (put into operation in August 1929). The bridge designed by Professor Stefan Bryła is a truss bridge with the deck below the arch, having a span length of 27 metres. The article discusses the technical condition of the bridge during non-destructive acceptance tests performed in 1929 and the results of diagnostic tests performed in 1958 and 1960 by the Gdańsk University of Technology and the West Pomeranian University of Technology in Szczecin.

Keywords: welded bridge, X-ray tests, test loads

DOI: *10.17729/ebis.2018.6/3*

Introduction

Because of the naturally progressing reduction of the load-carrying capacity of bridges after long-lasting operation, the assessment of their service life is of utmost importance. Article [1] discusses new specialist methods used to evaluate the load-carrying capacity of bridges in Canada, Great Britain, Denmark and Switzerland. Presently, in Poland the procedure related to the assessment of the useful load-carrying capacity of bridges is performed in accordance with instruction [2] and based on:

1. making of revised static-strength calculations and diagnostic tests,
2. subjecting bridges to test loads [3],
3. application of the simplified method.

The application of presently used criteria when assessing the load-carrying capacity of "old" bridges seems unjustified, ending up in qualifying them for unnecessary reinforcement or replacement [4, 5]. The most reliable assessment of the load-carrying capacity of bridges is obtained by performing diagnostic tests on an in-situ basis. The above-named tests enable the evaluation of the actual behaviour of a given structure based on intrinsic structural solutions. Types of tests and recommendations related to the test-aided design are discussed in the PN-EN 1990:2004/A1:2008 standard. The authors assert that results obtained during tests of historic bridges are particularly useful. An object discussed in the article is the world's first road truss welded bridge built along the national Warszawa-Poznań road, over the river Słudwia in the village of Maurzyce, near Łowicz, put into operation in August 1929 [6÷11].

The aforesaid bridge was in operation for 48 years, until 1977. Having a functional width of 5.40 m, the bridge impeded increasingly intense vehicular traffic. The bridge was moved

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up the river by 25 metres. Initially, the bridge was used as a by-pass bridge during the construction of a new wider bridge. Presently, the bridge is a historic monument and an exhibit of great value (Fig. 1).

Fig. 1. Historic bridge in Maurzyce

Bridge characteristics

Load-carrying girders of a single-span bridge (having a theoretical span length of 27.0 m and a height of 4.30 m at the half of the span length) are simply-supported trusses with the deck below the arch. The bridge was designed as the first-class bridge in accordance with road bridge-related regulations of the Ministry of Public Works of 1925. The bridge deck between the girders is 5.40 metres in width as pavements (being 1.50 m wide) are placed on brackets welded to the outside parts of the trusses. The deck of the bridge was designed as the beam deck with a slab made of reinforced concrete. The main view of the bridge, the schematic diagram of the truss girder and the cross-section of the bridge span are presented in Figures 1, 2 and 3.

The box sections of the truss chords were made of plates. Along their entire length, the upper and lower truss chords were made of the same vertical plates (370 mm × 12 mm in cross-section) (see Fig. 2). In the upper truss chord (hat-like in cross-section), the plates were joined using an upper horizontal plate having a width of 560 mm and a variable thickness ranging from 20 mm through 24 mm to 29 mm along the bridge length. At the bottom and on the outside, the plates were reinforced with an angle plate (90 mm ×90 mm ×11 mm). The lower truss chords, composed of two T-shaped elements, were provided with lower horizontal plates having dimensions of 190 mm × 12 mm in the two extreme panels and being 250 mm ×18 mm in the four remaining central panels. The truss posts were made of four angle plates (80 mm × 80 mm × 8 mm) welded to the web (continuous plate of 280 mm × 12 mm), whereas

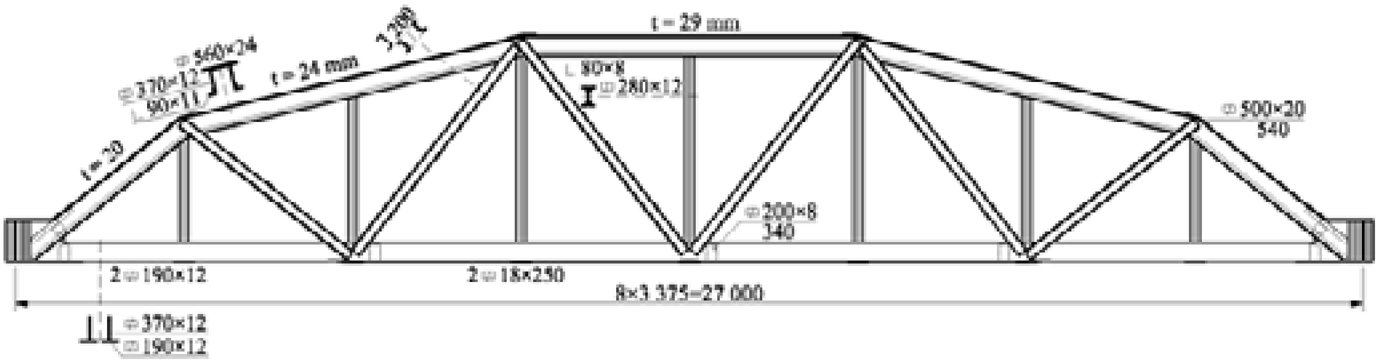


Fig. 2. Schematic diagram of the welded truss girder

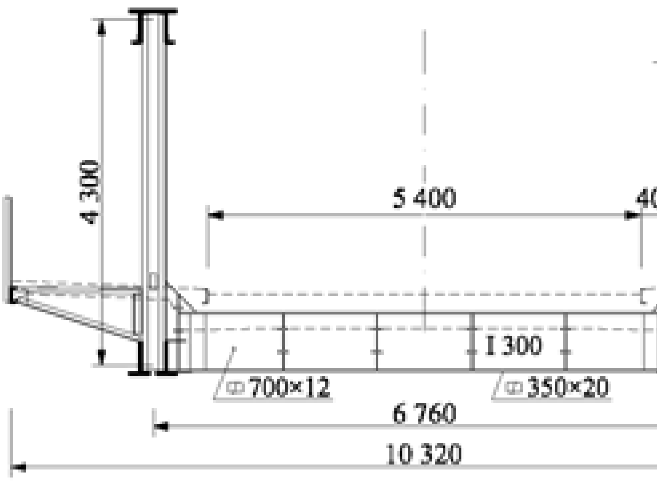


Fig. 3. Cross-section of the bridge span

cross braces were made of two C200 channel sections joined with lacings. The deck crossbars were made as welded plate girders having a web of 700 mm ×12 mm and chords of 350 mm × 20 mm, whereas the stringers were made of I300 I-sections.

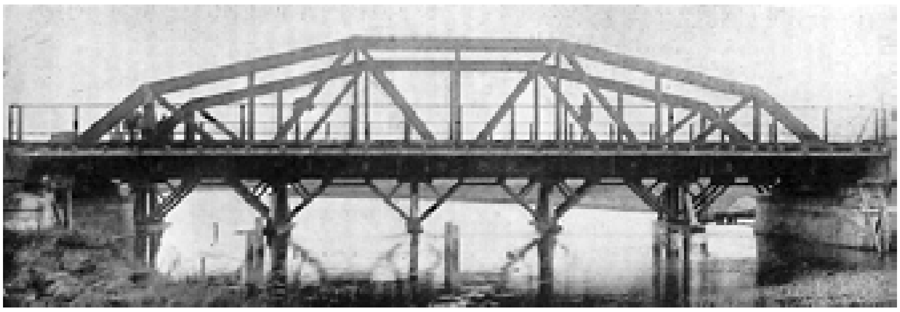


Fig. 4. Main view of the bridge during assembly in 1928 [8]

The assembly of the steel structure is presented in Fig. 4 and 5. The bridge span structure was made of cast steel characterised by strength restricted within the range of 370 MPa to 420 MPa and a minimum unitary elongation of 20%. Permissible strains in the steel adopted for the main girders amounted to 98.1 MPa, whereas those adopted for deck elements amounted to 81.5 MPa. The elements of the bridge structure were prefabricated at the K. Rudzki i S-ka Sp. Akc. (company) in Mińsk Mazowiecki.

Fig. 5. Assembly of the bridge deck in 1928 [8]

The joints in the bridge were welded and the Polish welders were trained by three welders from the Belgian *La Soudure Électrique Autogène* company (Arcos). The Belgian welders made all of the welded joints, both in the workshop and in the construction site. All of the joints were made using *Tensilend* (Belgian) electrodes.

After welding the span was lowered from scaffoldings onto bearings. The fixing of the span involved the precambering of the bridge amounting to 40 mm. After the lowering of the structure onto the bearings, the precambers in the truss girders amounted to 21 mm (upper water) and 20 mm (lower water).

Test loading on completion of the bridge construction [6]

The acceptance/commissioning of the bridge required the performance of strength tests under static and dynamic loads. In accordance with related regulations [12], the design moving load was identified in Figure 6 according to schematic diagram a), i.e. subjecting the bridge to a load involving the use of a 20 ton roller along a 6.0 m long section and a uniform load of 5 kN/m2 along the remaining sections, being 9.0 and 12.0 m in length. During the modelling of the above-named load, the adopted load with sand was that presented in schematic diagram b) of Figure 6. The bridge deck at the half of the span length, at a length of 6.0 m and across the entire width was subjected to a load exerted by a 0.8 m thick layer of sand. The remaining part of the deck and the pavements were covered by a sand layer having a thickness of 0.3 m. The entire design load amounted to 136.7 t, whereas the weight of the test load amounted to 139.0 t.

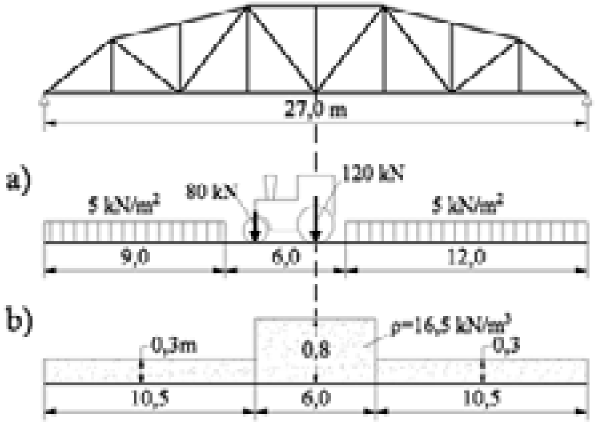


Fig. 6. Test loading of the bridge: a) load model according to [12], b) actual test loading

The loading of the span with sand started at 9.00 am on 10 August 1929 and finished at 5.30 pm. The maximum deflection at the half of the span (between the girders) amounted to 5.4 mm. At 11.00 pm the deflection reached 6.0 mm. The loading with the sand was continued until 7.00 am of the following day, with no increase in deflection being observed. After the removal of the sand, the girders were measured for permanent deflection, which amounted to 1.8 mm. Related static tests did not reveal any distortions or cracks in the bridge structure, which opened the possibility of performing dynamic tests involving the use of a 16 ton heavy steam roller. Maximum deflections in the girders measured during roller rides amounted to 1.7 mm (upper water) and 1.4 mm (lower water). The positive test results led to the acceptance of the bridge and putting it into operation by the public.

X-ray tests of the butt welds in the bridge

The 30 year-long operation of the bridge and its wartime damage (two times) necessitated the performance of X-ray tests of the welded butt joints of the structure; welds being the weakest element of welded structures. The tests were performed in 1958 by Katedra Konstrukcji Stalowych Politechniki Szczecińskiej /the Institute of Steel Structures of the West Pomeranian University of Technology/ [13]. The tests involved all of the butt welds in the principal load-bearing elements, i.e. the main girders (Fig. 7) as well as, partly, in the webs of the joints of the crossbars with the trusses. As can be seen in Fig. 2, all of the butt welds in the vertical plates of the lower bars of the trusses were covered with two-sided shoes being 200 mm × 8 mm in cross-section and having a height of 340 mm; in the upper chords: horizontal transverse welds being 20 mm and 24 mm thick, with a cover plate being 500 mm × 20 mm in cross-section and having a length of 540 mm. In turn, in the deck crossbars, the but joints of the webs were covered with two-sided shoes having the following dimensions: 200 mm × 10 mm x 700 mm. The total number of X-ray photographs, presented in Table 1, amounted to 76.

Fig. 7. X-ray tests of the butt joints of the upper chord: a) horizontal transverse weld; b) vertical weld

The X-ray photographs revealed the very low quality of the butt welds in the bridge structure. Out of 76 sections of the welds, as many as 72 contained welding imperfections representing quality level D or lower. The above-named number corresponded to 94.7% of the joints subjected to the tests. In turn, in 17 cases, welds contained longitudinal cracks. The aforesaid observations concerned particularly the horizontal transverse welds of the upper truss chords. The above-named welds (of thicknesses t = 20 and t = 24 mm) were covered by a one-sided shoe (500 mm × 20 mm in

Table 1. X-ray test results and quality levels related to butt joints

Tested element	In total		Number of X-ray photographs in relation to quality levels 1)			
	X-ray photographs	Cracks	B (R2)	C (R3)	D (R4)	>D (R5)
Lower truss chords	32	4	-	2	12	18
Upper truss joints	24	13	-	1	4	19
Webs of cross-bar joints	20	-	-	1	3	16
In total	76	17	-	4	19	53

1) X-rays were qualified as R1 ÷ R5, in accordance with the PN-M-69772 (Polish) standard (imperfection classes in parentheses); the classes are comparable with quality levels B+, B, C, D and > D according to PN-EN ISO 5917:2014

cross-section). The welds contained 13 longitudinal cracks, which corresponded to 54.12% of the sections of the welds subjected to the tests.

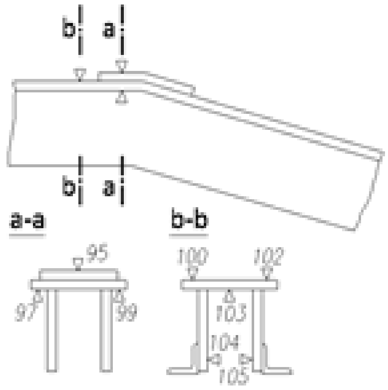
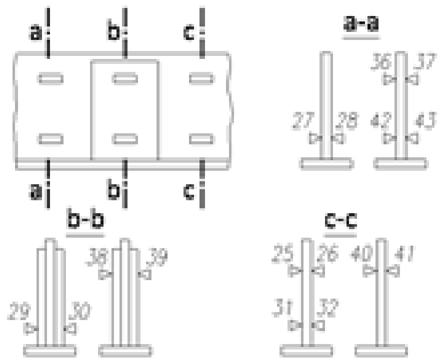
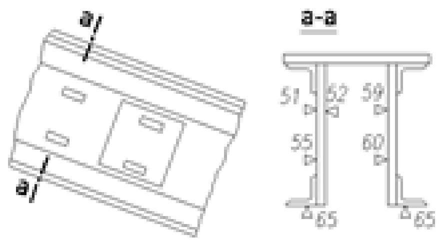
Verification test loadings of the bridge

Because of the low quality of the butt welded joints in the bridge structure, the authors of the article [13] commissioned the performance of static and dynamic tests of the bridge to assess its safe use. The tests involving the use of test loads and extensometric measurements of stresses in the load-bearing trusses were performed by Katedra Budownictwa Stalowego Politechniki Gdańskiej /Institute of Steel Building Engineering of the Gdańsk University of Technology/ in 1960. The loads used in the tests were two lorries filled with stones and having axial loads restricted within the range of 47.0 to 141 kN (Fig. 8). Stresses were measured on both girders K and M at six marked nodes, using three location arrangements (see Fig. 8). In each node, stresses subjected to measurements were those in the cross-section crossing the weld axis (gross cross-section reinforced with shoes or cover plates) as well as in the neighbouring net cross-sections outside the reinforcements. The values of stresses measured in individual measurement points are presented in Table II. The table also presents the stress value in relation to standard stresses in net cross-section (column 6).

The comparison of the values of measured and calculated stresses (columns 5 and 6 in Table II) in relation to the nodes of the upper chords (G3, G2, M0) of the bridge trusses revealed their compatibility. However, the foregoing did not apply to the nodes of the lower truss chords (K2, K3, M3), where measured stress values differed significantly from calculated results. The analysis of the phenomenon led to the conclusion whereby the bridge as a whole behaved in a spatial manner. The foregoing was confirmed by measurement results concerning stresses in one stringer located in the fragment of the bridge not exposed to the load. The values of stresses identified in the stringer constituted 84% of stresses present in an appropriate panel of the lower truss chord. Similarly, static calculations, taking into consideration the operation of the deck, identified stress values in nodes K2, K3 and M3 as amounting to 8.0 MPa, i.e. very similar to the value obtained in measurements -σ = 8.23 MPa.

The above-named assumptions were also confirmed by the analysis concerning the rigidity of the bridge structure. The maximum measured deflection of the girders amounted to 3.02 mm and was very close to the calculated deflection (including the deck operation) amounting to 2.96 mm.

Table 2. Measured and calculated stresses

Node [1)]	Cross-section	Point no.	σ (MPa) Measured	Mean	Calculated	Arrangement of measurement points
G3 (G2)	a-a gross	95	3.85	6.58	-	
		97	8.70			
		99	7.20			
	b-b net	100	11.62	11.80	11.30	
		102	11.30			
		103	11.50			
		104	13.10			
		105	11.50			
K2 (K3, M3)	b-b gross	29-30	4.08	3.94	-	
		38-39	3.80			
	a-a c-c net	25-26	8.04	8.23	17.3 (8.0) [2)]	
		27-28	8.80			
		31-32	7.82			
		36-37	7.96			
		40-41	8.12			
		42-43	8.62			
M0	b-b gross	58-59-60	7.06	7.48	-	
		66	7.90			
	a-a net	51	11.50	11.45	9.8	
		55	11.25			
		65	11.60			

[1)] results obtained in nodes (G2, K3, M3) were similar to those in G3 and K
[2)] stress calculated taking into consideration the operation of the deck

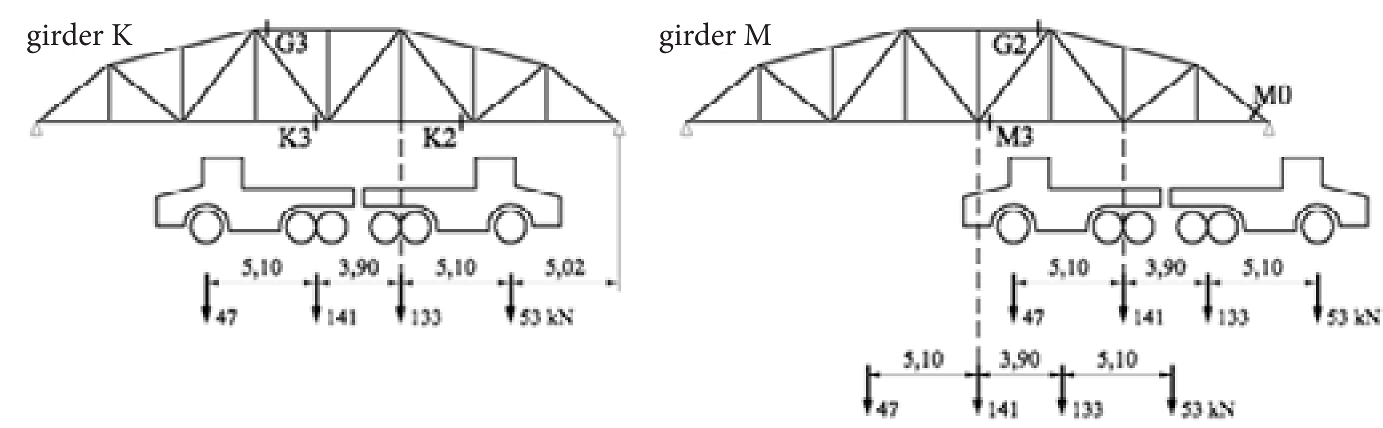


Fig. 8. Truss girders (K and M): test nodes and loading arrangements [14]

Summary

Taking into consideration the design solutions of the butt welded joints in the bridge combined with the low levels of stresses present in the bridge as well as the fatigue test results related to the welded joints [15, 16] it seems justified to recommend the further use of the bridge without reinforcement. The load test results revealed the significant rigidity of the truss welded span and the combined operation of the deck made of steel beams with the lower load-bearing truss chords. The slab of the deck made of reinforced concrete provided the structure with a stabilising effect.

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