Miśkiewicz M., Kozakiewicz A., Pyrzowski Ł., Sobczyk B.: Sustainable development requires risky decisions - problematic 300 ton overweight transport passing a bridge. **DOI: 10.2749/newdelhi.2023.0674** / IABSE Congress New Delhi 2023: Engineering for Sustainable Development, ISBN: 978-3-85748-200-7.
The publication is available in the online shop: https://www.iabse.org/Sys/Store/Products/348317

Sustainable development requires risky decisions - problematic 300 ton overweight transport passing a bridge

Mikołaj Miśkiewicz, Andrzej Kozakiewicz, Lukasz Pyrzowski, Bartosz Sobczyk
Gdańsk University of Technology, Gdańsk, Poland

Contact:mikolaj.miskiewicz@pg.edu.pl

Abstract

Oversize load passages over bridges are one of the research issues related to sustainable development that engineering and scientific teams around the world have to deal with . The article presents the scope of activities that enabled the passage of an oversized vehicle with a total weight of over 300 tons over a reinforced concrete slab. The bridge load capacity is 30 tons. In order to assess the capacity of the bridge, detailed visual inspection, inventory, tests during a load test, field and laboratory tests of concrete, location and inventory of reinforcement, static and strength calculations were carried out. Unfortunately, the tests done during the passage of an oversize vehicle on the bridge showed that the actual weight of the set were greater than originally declared. Fortunately, it turned out that there were still some reserves in the structure load-bearing capacity and the over-weighted vehicle entered the bridge without any damage to its structure.

Keywords: reinforced concrete bridge; oversized transport; FEM; GPR; load testing.

1 Introduction

One of the research issues related to sustainable development that engineering and scientific teams around the world have to deal with are oversize load passages over bridges. Many of them are several and sometimes even several dozen times heavier than the estimated usable load capacity of the bridge on which they intend to pass. In the case when archival documentation is available, the analysis of the permission for the abnormal transport is often limited to the calculation of the structure's response under the new, extraordinary load scheme only. Unfortunately, the archival documentation is often not preserved, especially for old bridges and those located along roads of minor importance. In such a case, approval of an overweight vehicle passage is quite complicated. The standard calculation and diagnostic methods used by engineersare not sufficient here. In this case, the issuing of a permit to pass the bridge requires a complementary scientific analysis of the structure response. The problem is extremely important, but quite rarely addressed by researchers [1]-[5]. Therefore, the aim of the paper is to present a representative methodology for assessing the load-bearing capacity of a bridge to allow the passage of an oversize vehicle. The case study presented here enabled the new power station generator to be delivered to the plant in the fastest way.

2 The description of the bridge

The road bridge crosses the Piasnica River in the Pomeranian Voivodeship in Poland. It is a two-span continuous reinforced concrete slab with a total length of 13,1 m (Figure 1). The theoretical spans length is $L_t = 2 \times 6{,}35$ m.

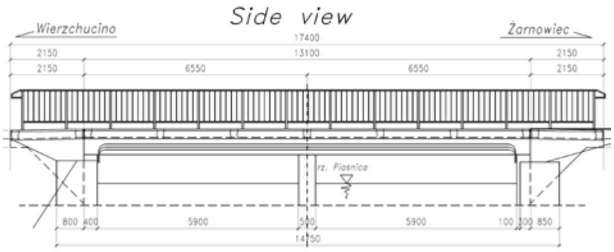

Figure 1. Side view

Reinforced concrete abutments and a pillar that is 0,5 m wide support the bridge. No bearings are used. The thickness of the slab is 0,5 m. The slab is equipped with sloping concrete, insulation and pavement surface (0,15 m thick). The total width of the bridge is 8,29 m and the usable width of the carriageway is defined as 7,05 m. Steel railings are attached on both sides of the structure. It is not known how the foundations were built.

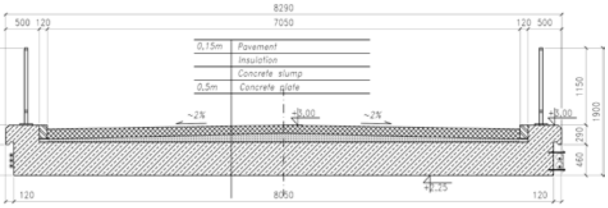

Figure 2. Cross section

Archival documentation of the bridge was not available. However, it possibly has been constructed in 1970s. The load capacity of the structure was determined to be 30 tonnes (300 kN) according to periodic inspection protocols [6]. However, information about analyzes done to estimate the capacity was not given in [6]. Therefore, the condition and load-bearing capacity of the bridge is to be determined on the basis of a detailed visual inspection, test loading and testing.

3 Detailed inspection

A detailed inspection of the bridge did not reveal severe cracking. Scratches or delamination would indicate a significant reduction of the load carrying capacity, namely suggest that the structure had been overloaded. However, numerous concrete losses, efflorescence and corrosion of the reinforcement were noticed on the underside of the concrete slab (Figure 3).

Figure 3. Bottom of the slab

This damage was evidently caused by leaking insulation. With regard to the supports, the cracking of the abutment wing and its waterlogging by rainwater were identified as the most significant damages.

4 Load testing

The main reason of the proof loading was to check the behaviour of the bridge. Different loading schemes were applied to induce a condition corresponding to the declared load capacity of the bridge in the individual elements of the structure (span, pillar, abutment). The response turned out to be elastic , in accordance with theoretical predictions, thus further diagnostic works were launched. These were aimed at permitting and defining the conditions for a single passage of an abnormal vehicle with a declared total weight of 300 t. The tests were preceded by a basic static analysis of the bridge with reference to the standard [6].

The loading test was carried out using 2 3-axle trucks with a total mass of 33 tonnes each and 2 4-axle trucks each having a mass of 40 tonnes. The trucks were positioned on the bridge according to five different arrangement configurations. These were aimed to induce extreme values of reaction forces over the supports and bending moments at the mid-span and over the support as well. Examples of vehicle alignments are shown in Figure 4.

Figure 4. Test load settings: top - inducing a minimum bending moment over the intermediate support, bottom - inducing a maximum span bending moment

Displacements were measured during the tests using precision levelers and inductive sensors in the locations shown in Figure 5. In addition, vibrating wire strain gauges were attached at the mid-span..

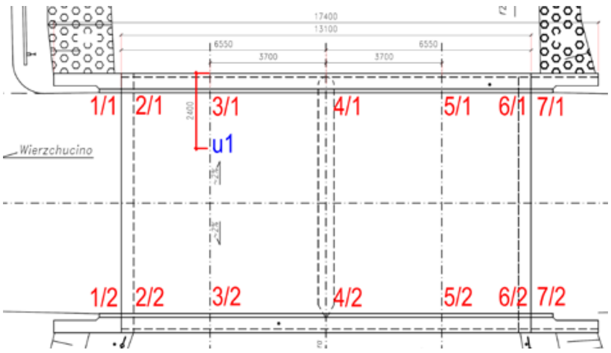

Figure 5. Displacement measurement points

The measured extreme values of displacements and deformation of the span during the static tests were lower than the theoretical values (Table 1).

Table 1. Vertical displacements in the middle of the span

Measuring point	Measured (M) [mm]	Calculated (C) [mm]	M/C [%]
5/2	0,60	0,74	81
5/1	0,40	0,45	89

Measurements of the supports settlements during the testing procedure did not reveal any abnormal behavior. Visual inspection of the structure did not reveal any new damage that could have been caused by the test loads as well. Static test results confirmed the elastic behaviour of the bridge, as intended. Experimental analysis confirmed the ability of the structure to carry loads even higher than 30 tonnes.

5 Identification of the materials

The main aim of this part of the research was to check whether severe degradation processes in concrete have begun. Identification of the amount and distribution of the reinforcement in the slab were conducted as well. In consequence, the following actions were undertaken: concrete specimens chemical compositiontesting, concrete strength determination , concrete reinforcement scanning.

5.1 Chemical testing

The chemical tests were designed to check the pH value and the content and level of Cl^- and SO_4^{2-} ions in the concrete. The lowest pH value reported during the tests was 10,7. This indicates a slight carbonization, which may be the cause of the loss of material ressistance to the progression of corrosion processes. The content of Cl^- and SO_4^{2-} ions did not exceed the typical corrosive limits..

5.2 Concrete strength

Two core boreholes were drilled, each with a diameter of 100mm, from the slab in above the abutments. Both were used to prepare cylindrical samples to for the compressive strength testing . The guaranteed strength determined in the tests was 23 MPa However, due to the standard regulations, f_c=12,8 MPa was used in calculations. Sclerometric tests confirmed that the slab concrete was homogeneous.

5.3 Reinforcement

Non-destructive field testing was done to determine the amount of reinforcement in the slabVisible reinforcement at the bottom of the slab was (Figure 3) counted. Scanning of the slab from above was done using GPR technology to inventory the upper slab reinforcement.

Visual inspection revealed that the slab at the mid-span is reinforced with Ø20 smooth rods with spacing between the bars to be approximately 10 cm. It was assumed that the reinforcing steel has the properties of the A-0 class material (f_d=190 MPa).

. The GPR methods, used to determine the amount of reinforcement above the support, is based on the principle of electromagnetic (EM) wave scattering and allows identification of the location of objects submerged within a homogeneous medium. The GPR transmitter sends out single, pulses of electromagnetic waves (t ≤1 ns), which are reflected by the receiver. The reflection of the electromagnetic wave indicates a change in the medium being analysed, which in turn, in the case of a reinforced concrete structure, allows determination of the reinforcement location. A total number of 10 scans was required to identify the arrangement of the rebar above the pillar. The results indicate that every second bottom plate reinforcing bar in the mid-span zone is bent in the upward direction and becomes upper slab reinforcement in the zone over the support. Some additional bars are present over the supports as well (Figure 6).

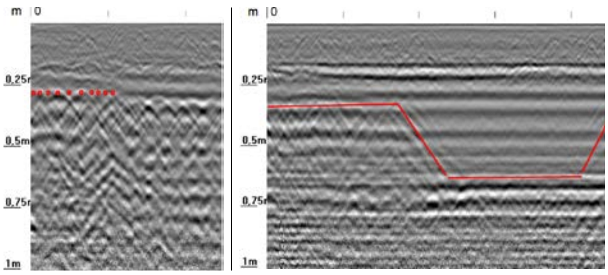

Figure 6. GPR scans of the bridge slab across the road above the pillar (left) and along the road at the kerb (right). The layout of the main reinforcement bars is shown in red

In consequence, the upper reinforcement above the abutments is Ø20, while the spacing between the rods is 10 cm.

6 Computational analyses

The main purpose of the computational analyzes was to determine whether it is possible to safely drive an oversize vehicle through the structure in its current state. Static calculations were carried out, in the linear and non-linear range, to take the current state of the bridge into account. The tested material properties of the superstructure were taken into account. Dimensioning was carried out according to [7].

6.1 Computational simulations

The calculations were carried out using the finite element method (FEM). The computational models were creating using the data collected in the test described above. Shell elements were used to build the model of the slab. The mesh contains 2747 nodes. Elastic elements were used to account for the actual response of the structure at the central support.

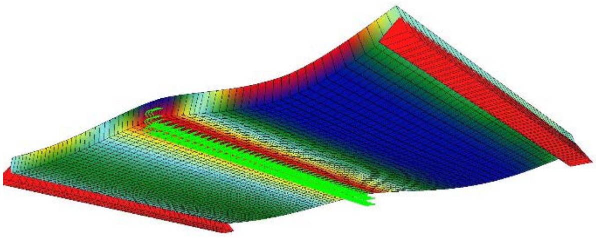

Figure 7. Visualisations of the deformation of the FEM model used for the calculations

For the model, 2-dimensional, 4-node shell finite elements of the Timoshenko-Reissner type were used. These are class C^0 elements with bilinear shape functions with enrichment of the deformation state in the surface eliminating the locking effect. These FE take into account the shear effect and the variation of the position of the shell reference surface (eccentricity).

The calculations included constant loads, moving loads in accordance with [6], the test load schedules and an above-standard vehicle. The oversize vehicle consisted of a FAUN tractor (8x8) and a COMETTO-1M semi-trailer with a total weight of 300 t and axle loads from 6 t to 19.45 t (*Figure 8*).

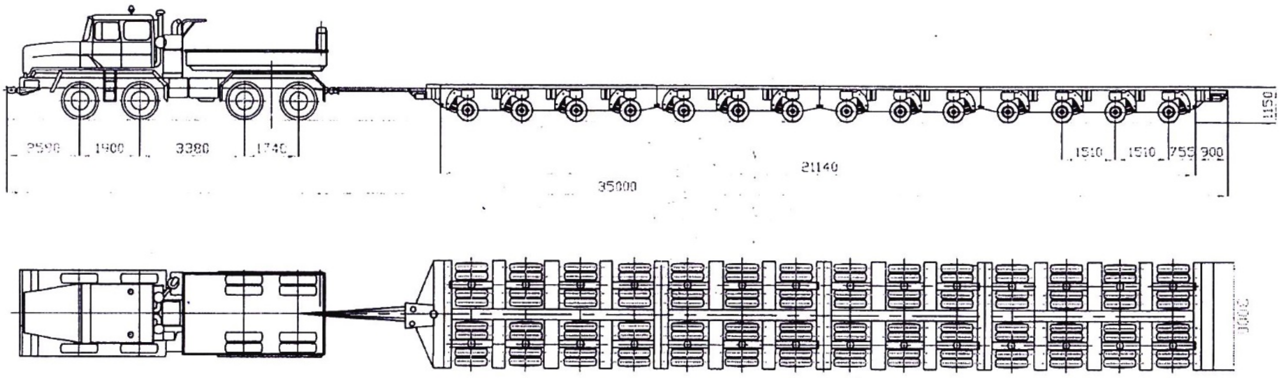

Figure 8. The oversize vehicle

It is assumed in the calculations, that the passage of the oversize vehicle will take place in the middle of the road. It will be travelling at a maximum speed of 10 km/h. In addition, it was assumed that other traffic is not allowed to enter the bridge, while the special transport is passing by The dispersal of the wheel load through the pavement and concrete was taken at a spread-to-depth ratio of 1 horizontally to 1 vertically, down to the level of the centroid of the

slab. The influence of the possible bonding between the sloping concrete and the slab was neglected.

In order to give a positive opinion on the feasibility of the overweight transport run, it was assumed that the internal forces/stresses/support reactions/displacements created by the vehicle and the trailer should be lower than the same quantities induced by the standard loads and/or the most unfavourable testing load scheme. Nevertheless some additional computational analyses were performed taking into account the non-linear behaviour of the materials to fully estimate the response of the concrete slab.

6.2 Results

Extreme internal forces (bending moments, shear forces), resultant support reactions and stresses in representative sections of the structure (span centre, pillar, abutments) were compiled as a result of the FEM analyses carried out in the linear range.

Table 2. Stresses in the deck slab in the middle of the span

Load case	σ_{steel} (S) [MPa]	$\sigma_{concrete}$ (C) [MPa]	S/f_d [%]	C/f_c [%]
DL + standard load	121	-5,9	64	46
DL + test loading	96	-4,6	50	36
DL + overweight load	103	-5,0	54	39

The results of the static calculations showed that all the internal forces in the bridge during the oversize passage are lower than the values generated by the standard design loads or the testing load. However, the calculations showed that the maximum reaction force during the abnormal passage, is 2586 kN, while the typical design load creates 2326 kN and the testing load 2269 kN. The displacement of the bridge at the u1 point (Figure 5) is 0,69 mm.

Representative stress maps determined by non-linear calculations for the passage of an oversize vehicle are shown in the Figure 9.

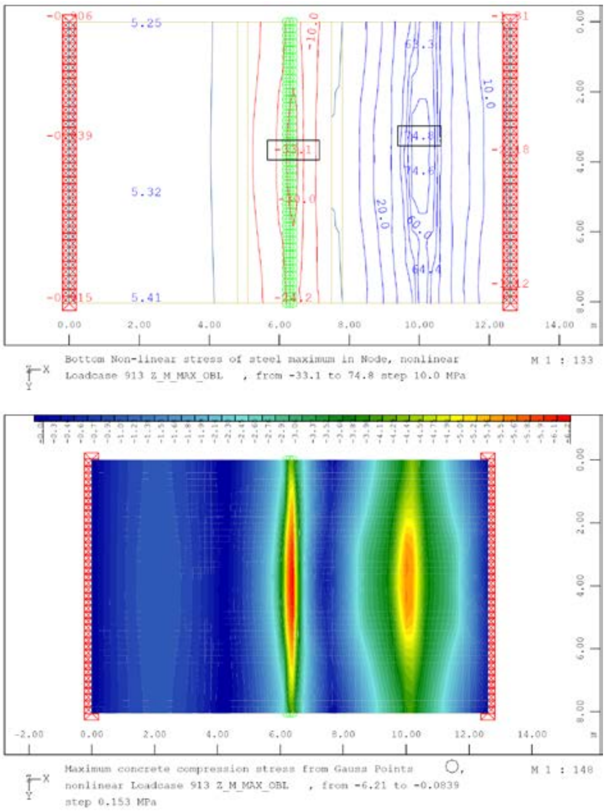

Figure 9. Stresses in the slab during the passage of an oversize vehicle: top (isolines) and bottom (isoarea)

7 Oversize crossing

7.1 Decision

Finally, after a complete set of diagnostic work and computational simulations, permission was given to proceed with the crossing under several conditions. Firstly, it was recommended that the passage must be piloted, take place exactly along the center line of the road and its speed must not exceed 10 km/h. Secondly, it was recommended that the geometry and axle loads of the transport vehicle set should be strictly controlled. Thirdly, it was necessary to remove any obstacles from the bridge that could cause additional and unwanted load increase due to dynamic effects. What is more, due to the condition of the structure, detailed inspections were recommended immediately before and after the crossing. Moreover, since the extreme reaction was exceeded by 11% and the details about foundation method was missing, it was recommended to perform monitoring of the bridge supports during the crossing. The oversize vehicle is shown in *Figure 10*.

Figure 10. The oversize vehicle before driving onto the bridge

7.2 Technical monitoring

As recommended, bridge surveys were carried out during the passage. These included settlement measurements of the supports and technical monitoring of the span vertical displacement. The settlement measurements showed the occurrence of settlement of the supports approximately 0,2 mm. The extreme total vertical displacement of the span was 1,16 mm and the elastic deflection was 0,96 mm. The deflection registered during the passage of the non-standard vehicle (*Figure 11*) confirmed that it was done in accordance with the assumptions and all the dynamic effects were negligible.

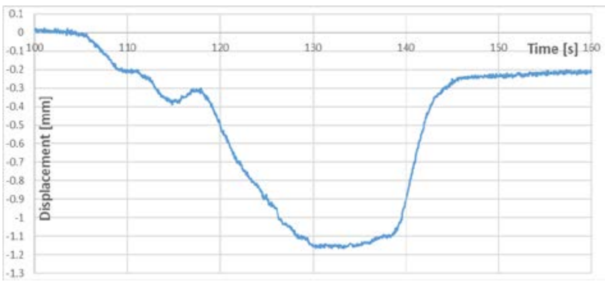

Figure 11. Graph of the change in displacement at point U1 (Figure 5) *from the oversized crossing*

It turned out that the recorded displacement values at the u1 point were about 25% higher than those obtained from the numerical simulations. This behaviour of the bridge was particularly puzzling because a validation of the calculation model was carried out on the basis of the results from the testing load. It was therefore possible to conclude that the vehicle weight, axle loads and thus the impact on the bridge could have been up to 25% higher than declared by the Company applyingfor the transport permit. Fortunately, the structure and the materials used for its construction still revealed additional load-bearing reserves and the bridge structure was not damaged. The inspections carried out after the pass was finished did not indicate any new damage to the structure. In addition, the test results confirmed that the bridge response is appropriate, i.e. lies within the elastic range, during the abnormal vehicle passage.

8 Conclusions

The article succinctly outlines the extent of the work that was required to allow passage of an oversize vehicle with a declared total mass of 300 tonnes through over a 40-year old bridge, whose declared load capacity was 30 tonnes. Unfortunately, the tests carried out indicated that the actual impact of the transport on the structure may have been up to 25% greater than predicted in calculations. These unique results indicate possible inaccuracies in the assessment of the weight of the load transported by the oversize vehicle and trailer. In the case of analogous extremely risky passages, it seems that it necessary to measure the axle loads of the convoy before allowing them to enter traffic. In this case, it was possible to deliver new power station generator to the plant and provide local consumers with access to electricity. The test results analysis suggests that the bridge almost reached its limit load capacity. As no new damage of the bridge was observed after the passage, it is however likely that this did not happen due to material strength reserves and additional bonding between the sloping concrete and the slab, which were not included in the FEM simulations.

9 References

[1] Abedin M, Mehrabi A. B., Azizinamini A., Ghosn M, Nowak A.S., Ramesh Babu A. Reliability evaluation of twin steel box girder bridges using a simplified method. Engineering Structures. 2022; 259:114122.

[2] Ho Choi H., Kwon Lim J., Won Seo J., and Ki Jung P.. An Overweight Permit Analysis System for Bridge Management. KSCE Journal of Civil Engineering. 2006; 10 (2): 123-129.

[3] Huang P., Wang J., Han W., and Yuan Y. Study on impact factors of small- and medium-span bridges under the special-purpose vehicle load. Structures. 2022; 43: 606-620.

[4] Sofi F. A. and Steelman J.A. Using committees of artificial neural networks with finite element modelling for steel girder bridge load rating estimation. Structures. 2021; 33:533-553.

[5] Zhu Z., Xiang Z., Lic J., Huang Y., and Ruan S. Fatigue behavior of orthotropic bridge decks with two types of cutout geometry based on field monitoring and FEM analysis. Engineering Structures. 2020; 209: 109926.

[6] PN-85/S-10030 Bridge structures. Loads. *(in Polish)*

[7] PN-91/S-10042 Bridge structures. Concrete, reinforced and prestressed structures. Design. *(in Polish)*