DESIGN AND CONSTRUCTION OF THE RAILWAY BRIDGE STRUCTURE AT KM 41+351 OF THE LK116 RAILWAY LINE

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Introduction

Soil–steel composite structures have become a permanent fixture in the Polish infrastructure market. They were used for the first time in Poland in the late 1970s (at the Borne Sulinowo military base) and have become ever more common over time, peaking in popularity in the last 20 years. Common on the Polish road network, both short and long-span structures are also being increasingly used on the railway network. The growing popularity of buried bridges is due to a number of factors, including the simple and relatively fast design process, straightforward construction, and excellent value for money.

Photograph 1. The structure before reconstruction. General view of the bridge. Sliding roller bearing.

Photograph 2. Visible corrosive infiltrations.

The positive experiences of investors, contractors, and designers have borne fruit in shared success. Initially, short spans were designed and built. With time, however, solutions were found to enable ever larger spans. This paper presents selected aspects of the design and construction process of a long-span railway bridge.

Characteristics of the structure

Railway Line No. 216, from Działdowo to Olsztyn (Poland), in the section in question, is a single-track, first-tier line. The structure at km 41+351 was built in 1888. In 1955, it was rebuilt as an inverted bowstring truss structure with a theoretical span of L = 39.66 m. The main girders are spaced 4.0 m apart. The structure of the existing bridge was entirely riveted.

The structure's condition was found to be unsatisfactory, with numerous instances of damage to the anticorrosion coating and corrosion of structural elements, in particular the bottom chord. The lower flanges of the structural elements were largely reinforced with cover plates. Sites of deformation and corrosion were found in the wind braces of the bottom flanges. The roller bearings also showed signs of local corrosion and were also quite dirty.

The structure's abutments were in a good condition but showed a network of surface cracks and damage to the pointing and were heavily overgrown with moss. In addition, the stone part showed salt deposits in places.

Design

In order to assess the structural strength capacity, a static analysis of the bridge was performed. The design process was preceded by laboratory analysis of the materials used to construct the bridge.

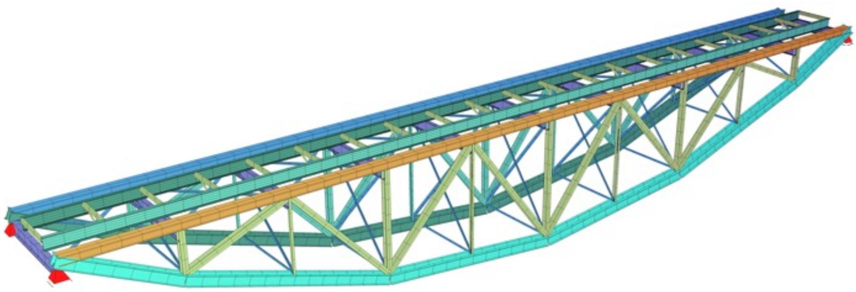


Figure 1. Visualisation of the computational model of the structure—axonometric view.

As part of these calculations, it was found that the maximum stresses (tensile stresses, compressive stresses, and reduced von Mises stresses) were exceeded for all structural elements of the bridge. The bridge would not be able to withstand loads of type C2 and D4 at the required speed of 120 km/h for passenger trains and 80 km/h for cargo trains. In line with investor recommendations, the engineering structure was designed in accordance with the Technical Standards[3].

Given the results of the calculations performed and the properties of weldable steel, it was recommended that the structure be replaced with a new one.

The order implementation sought to achieve the set of operating parameters in accordance with the railway line category.

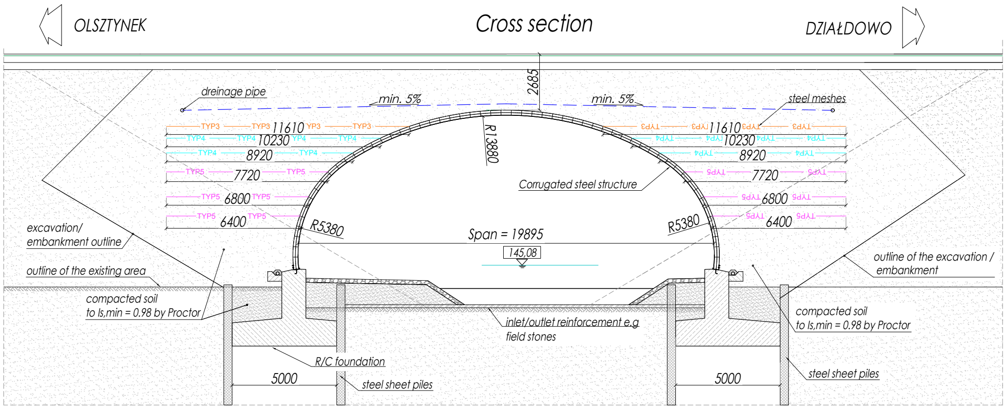


Figure 2. Cross-section of new designed structure.

Given the significant load (in accordance with LM 71 for Class K+2) and the quite large span dimension, the structure was always going to be remarkable. Only two structures have been built so far with a span of more than 10.0 m anywhere on the Polish railway network. It should be noted that the record for the longest span to date was held by a structure in Świdnica (span of 14.96 m). Given their structural characteristics, arches of various types are a sensible design choice for long spans. They can take the form of a regular (single radius) arch, or a low-profile arch, with a top (larger) radius and a side (smaller) one.

This structure was designed in the form of a low-profile arch with geometric parameters as set out in Table 1.

Name of the parameter	Symbol	Unit	Value
Profile symbol			UC-23NA
Span of the structure	D	m	19.82
Rise	H	m	7.37
Height of cover	H_c	m	2.28
Top radius	R_t	m	13.88
Side radius	R_s	m	5.38

Table 1. Geometric parameters of the shell structure.

This shape is what enables the construction of the bridge. To build a single-radius arch with a span of 20 m, we would need a very high embankment of at least the rise of the structure (half of its span, i.e., 10.0 m), plus soil cover with a height of around 3.0–3.5 m, producing a total height of approximately 13.0 m. However, such terrain can be found only in mountainous areas, where there are many deep valleys or even ravines, whilst the bridge this paper concerns was built in the low-lying area around the town of Olsztynek (Maróz), Poland. The distance measured from the head of the track to the terrain level was lower than this mentioned before at just 9.65 m.

The sophisticated numerical analysis was used to optimise the solution, i.e., to determine the height of cover, so as to minimise the thickness of the steel profile as much as possible (obviously ensuring both ultimate and serviceability limit states).

The calculation was performed using the finite element method (FEM) in PLAXIS 2D software, 2010 version, with one- and two-dimensional elements in a two-dimensional space ($e^{1+2}p^2$). The 1-D elements (plates) were used to model the structural shell and the foundation elements. The 2-D elements (soil polygons) were used to model the structural backfill, the track design, the railway embankment, and the soil base. The interactions between the structural backfill and the UltraCor structure and between the backfill and the foundation wall were modelled using interface elements.

A two-dimensional model was used due to the strong orthotropy of the structural elements combined with the uniform geometry along the structure. The prepared finite element model represented the entire construction process, starting from the assembly of the structure, throughout the backfilling and compacting processes, construction of the railroad superstructure, to the service stage. The model was

[3]Detailed technical conditions for the modernisation or construction of railway lines up to a speed of V_{max} ≤ 200 km/h (for standard rolling stock) / 250 km/h (for rolling stock with a tilting car design). Version 1.1, Warsaw, 2009.

verified at every stage, particularly in the two characteristic phases:

- The stage of maximum upward deflection of the structure crown point ('peaking'), which is reached once structural backfill is applied up to the level of the shell's crown point

- The service stage, which involves dead loads and other permanent elements above the crown of the structure up to the level of the road superstructure, plus the live loads applied at the most unfavourable point (with regard to the level of stresses).

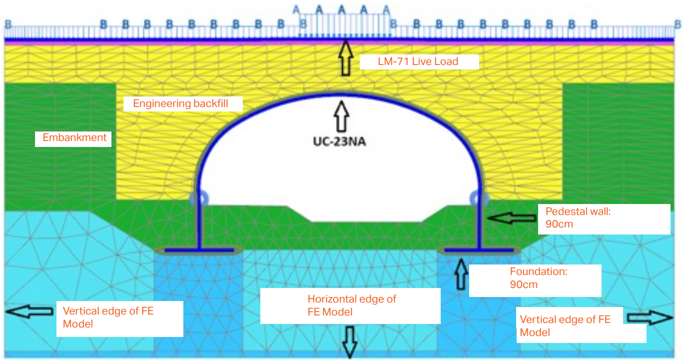
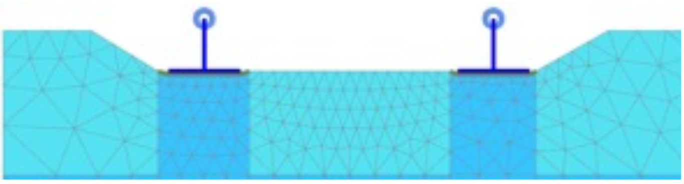
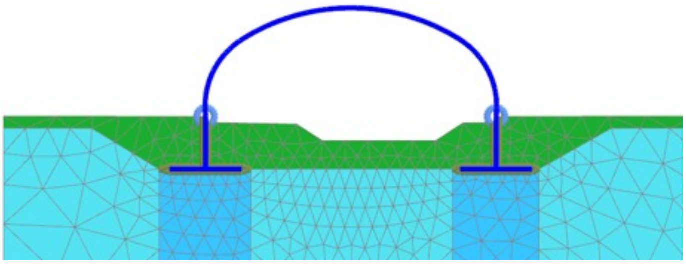


Figure 3. Computational scheme—numerical model.

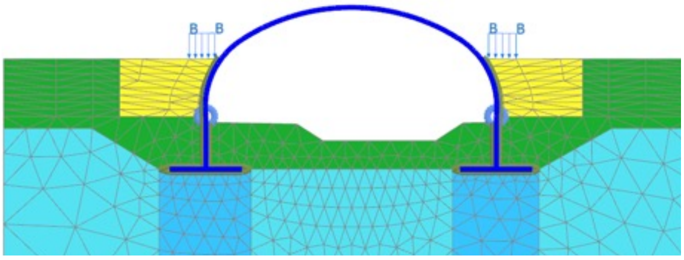
In the computational model, the entire construction process was analyzed, including individual stages of the backfilling process.



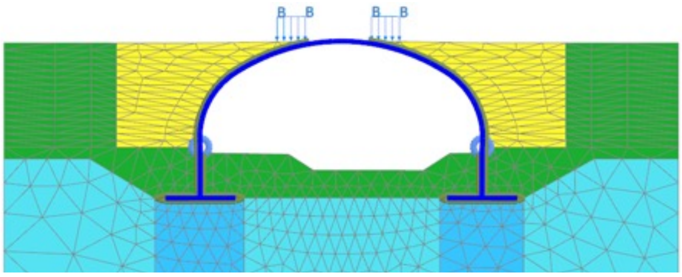
Building the supports of the soil–steel composite structure.



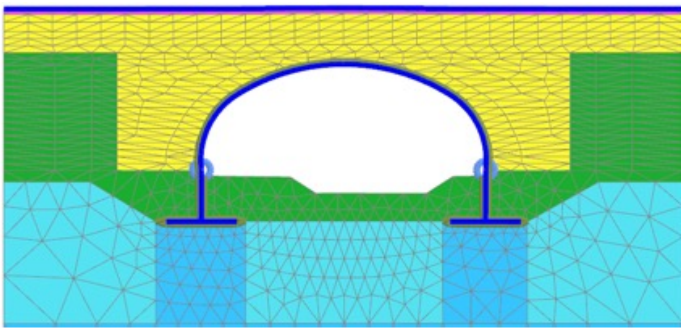
Assembly of the steel shell.



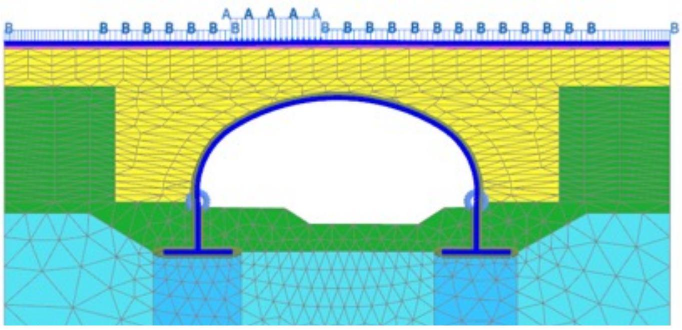
The structural backfill application stage. We took into account the technological loads caused by the compaction equipment, up to the level of the crown of the structure, where their effect can prove unfavourable.



The stage of the structure maximum upward deflection ('peaking'), which is reached once structural backfill is applied up to the level of the shell's crown point.



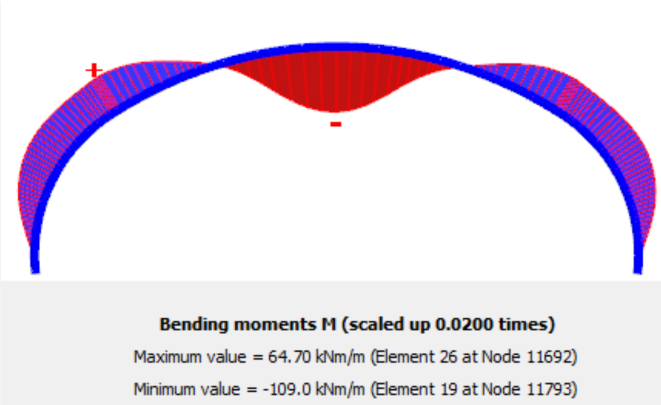
The dead load stage. The railway embankment is built up to the design ordinate, together with the track superstructure.



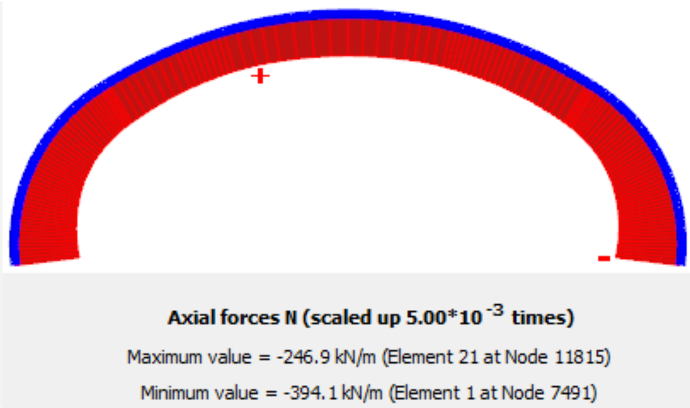
The live load (LL) stage—the aforementioned stage plus variable loads applied at 19 different schemes, to find the least favourable combination of internal force values given the section stress and the footing reaction value. Example load positions are set out below:

The analysis gave us the following internal force values.

1. The stage of the structure maximum upward deflection ('peaking')

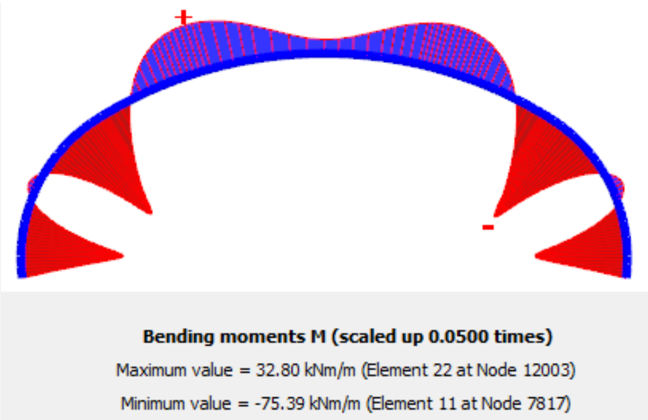


Bending moments

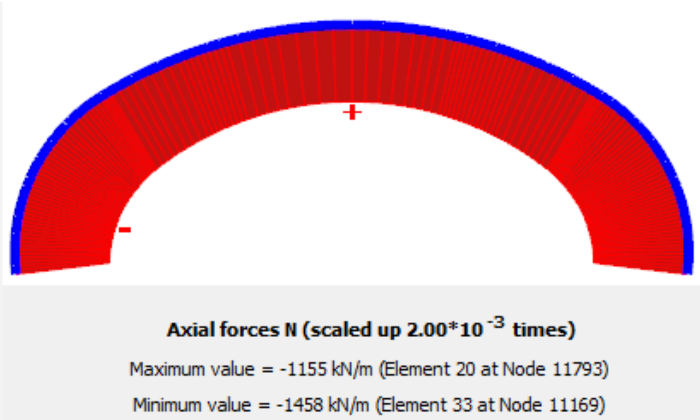


Axial forces

2. Dead load stage

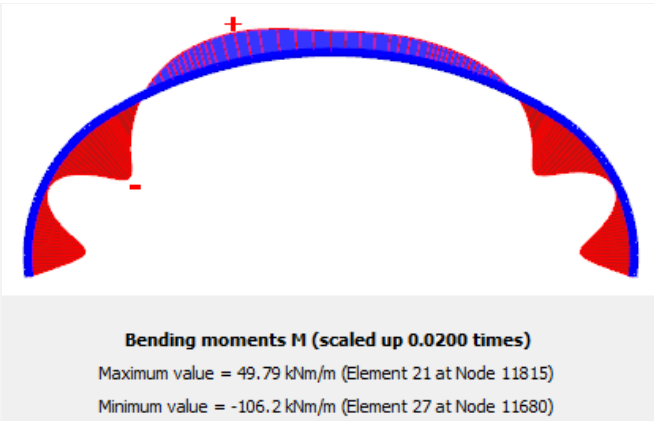


Bending moments

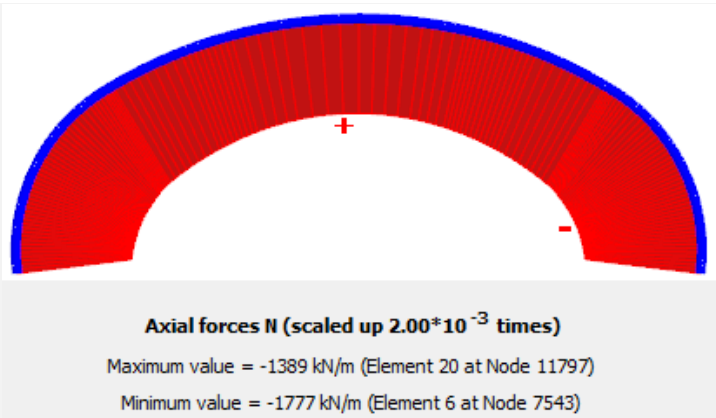


Axial forces

3. Live load (LL) stage (dead + live loads)



Bending moments



Axial forces

Construction

Several difficulties were encountered during the assembly of the steel structure that had to be overcome during the construction process.

Firstly, assembly took place under an electrified overhead line, with existing traction. Although the power was cut, particular attention had to be paid to the line during crane operation in order not to damage it.

The next difficulty was the size of the assembly area. The structure was due to be built in a cut, but the water was constantly flowing through the middle of the conduit, which meant that the assembly area was always wet. Consequently, the crane delivering the metal sheets could be positioned only at a single, paved site. Unfortunately, this site was located close to one of the corners of the structure. The crane, therefore, had to be secured in such a way that it could deliver the structural plates across a significant range (diagonally to the foundations).

All assembly work was carried out using basket lifts, for which working platforms also had to be prepared so that workers could assemble the structures safely. This was challenging, as the water was constantly undermining the paved area.

The assembly was started furthest from the crane. Successive elements were then added gradually. It was very soon found that, apart from the wet ground, the assembly workers also had to overcome other difficulties in connection with the terrain. The elements could only be transported to the edge of the forest, whereas the construction work was taking place approximately 2 km from the site. Consequently, further plants had to be used for transportation, in the form of off-road telehandlers, which gradually brought in the material needed for the construction work.

Photogra ph 3. Assembly work.

Photograph 4. Assembled steel shell.

Photograph 5. The new structure.

Particular attention had to be paid during assembly work especially of the structure's bevelled parts. The single-shell structure, across which trains were due to run (top length), was only 11.46 m long. In comparison with the whole length of the structure, this was just one-third of the entire bridge's length of 30.66 m.

The bridge was delivered for use subject to a number of conditions. The contractor still has one more task to perform: carrying out a live load test. The results of this test will supply further information about the behaviour of soil–steel composite structures subject to high-intensity live-load loads (with regard to both internal force values and dynamic effects).

Summary

The case study presented in this paper shows how a technically dilapidated structure in hard-to-access terrain could be rebuilt in such a way as to keep construction costs to a reasonable level whilst ensuring that it would be able to fulfil its function in accordance with the customer's expectations.

• The main driver in terms of the structural life cycle is that service costs are minimal. It has no bearings or expansion joints and no transition slabs, which are structural elements that require maintenance, servicing, or even periodic replacement.

• In the case of steel shells, it is vital to monitor the condition of the anticorrosion layers and respond promptly if damage is spotted. Experience shows that structures of this type do not show signs of corrosion for a very long time and can be used safely without any fear of their load-bearing characteristics deteriorating.

• An additional advantage is that, at the end of its anticipated useful economic life, the structure can be completely recycled, with the shell being replaced with a new one, whilst the surrounding structural backfill can be reused.

References

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