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CONSTRUCTION OF RAILWAY BRIDGES MADE OF FLEXIBLE STRUCTURAL PLATES. LIVE LOAD TEST[1]

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The first part of the presentation presents the construction of flexible steel plate structures on double railway tracks. The presentation explains the issue of a two-stage construction method illustrated examples from Polish construction sites. In the second part of presentation the author shows results of load tests under heavy railway loads compared against FEM results. Information about displacement of flexible steel plate structures under live loads is presented.

1. INTRODUCTION

In recent years, railway infrastructure in Poland has been undergoing comprehensive modernization. Construction works carried out on single and double railway tracks are intended at restoring and improving the parameters of the existing rail network and the associated infrastructure. Such a situation creates excellent opportunities for research and development in the area of construction of soil steel composite bridges.

Investors expect that contractors will work without track closure, using the two-stage construction method. This involves a complicated and lengthy rebuilding process. Construction work contractor are required to adequately protect deep trenches and exposed edges to ensure the safety of the construction works on railway bridges.

All bridge structures, including soil steel composite bridges, undergo live load tests.

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2. METHODS OF AND PROBLEMS IN CONSTRUCTING FLEXIBLE STEEL PLATES ON DOUBLE RAILWAY TRACKS

2.1. Sheet piling between the tracks

According to the Polish regulations, the distance between track axes is 4.0 – to 4.5m, which significantly limits the working space available between the tracks. Prior to removing the track and performing excavation works, sheet rolled piles are driven into the ground, mainly during night-time track closures . If the height of the excavation structure is significant, use of anchors might be additionally required. It can be done by pulling sheet piles outside of the railway track and connecting them with one pulled in the middle of the track. From a technical perspective, the whole procedure of securing a rail track is relatively simple. Most problems are caused by limitations of night-time track closures of the track and catenary voltage outages. Investors typically agree to close the track at night, but such closures do not last longer than 2-3 hours. Investors additionally require protection of the active track by temporary structures known as the "Swiss relieving construction" (Figure 1) in the case of large displacements of sheet piling in the direction of the excavation.

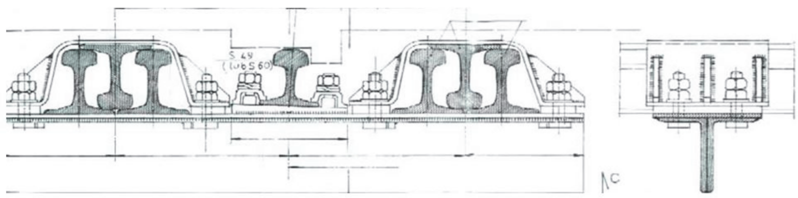

Figure 1. Cross section of the Swiss relieving construction

2.2.1. Works involving pulling out sheet pilling from between the railway tracks

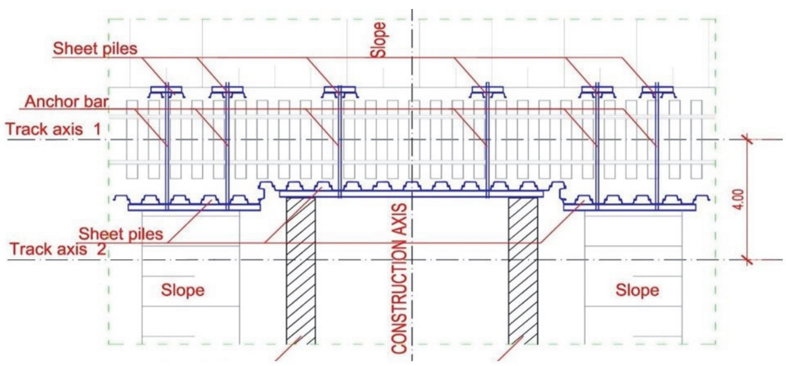

Figure 2. Top view of stage 1

A sheet pile wall is driven as close as possible to the active track. This location is critical in terms of connecting both parts of structure in the second phase of the works. Constructing a steel composite bridges in this way is divided into two stages. In the first stage (Figure 2) steel construction is mounted to the face of sheet pile wall. Before backfilling it is necessary to protect the structure's exposed edge on the intertrack side. Wooden beams (lost) or soil reinforced with geotextiles can be used. Once the exposed edge of the structure is adequately protected, backfilling can begin and the dismantled track can be restored to the final stage.

In the second stage, the contractor proceeds with railway track disassembly. Subsequently the sheet piling can be pulled out. The exposed edge, properly secured in the first step does not allow the soil to leak out of the track. When excavation and foundations works are finished, the contractor proceeds to assemble the second half of the steel structure. Arguably, the biggest challenge at this stage is connecting both parts of the structure because the one built in the first phase could become deformed as a result of the backfilling process. Live load deformations are not a problem as they are always within the elastic range. If deformations caused during construction are small, there is no problem with connecting the two halves. One downside of this method could be soil loosening, caused when sheet piling is pulled out. This can have an impact not only on the track performance, but also on the foundation and backfillilling of steel composite structures.

2.1.2. Works involving leaving sheet piling in between the railway tracks

Leaving the sheet pile wall in place is a method that can also be used for two-stage construction of structures on double railway tracks which do not suffer from significant deformation during backfilling. This kind of solution is appropriate as long as the contractor reinforces the sheet piling over the crown and around the structure. Steel profiles such as IPE or HEB connected to sheet piles driven outside the railway track can be used as reinforcements. Before the contractor proceeds to the backfilling process it is necessary to use geotextiles to prevent the backfilling material from becoming loose. In the second stage, once excavation and foundation works are finished, the contractor cuts a hole in the outer contour of the steel sheet pile wall, which makes it possible to finish the steel structure assembly. During backfilling, sheet piling protections should be dismantled.

3.1. Temporary bridge beams

To construct corrugated steel plates with cover depth of at least 3m and spans greater than 8m, contractors can use temporary bridge beams. This method is also highly recommended when skew angle is not around 90 degree and does not allow for using a two-stage construction method. Contractors usually use temporary bridge beams with spans of 15 to 32m, depending on the CSS span and cover height (Figure 3). In the case of structures with a greater span it might be necessary to use sheet piles to protect temporary cages.

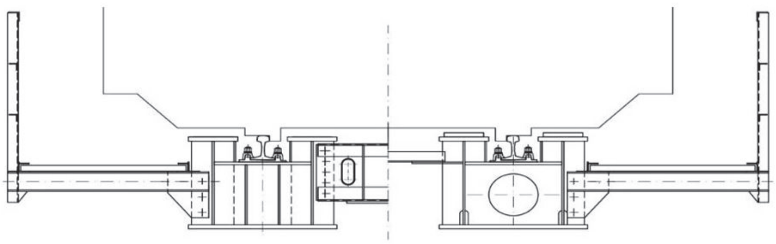

Figure 3. Cross section of temporary bridge beams

Construction works start with the disassembly of one of the railways track and preparing a temporary foundation made of wooden sleepers fastened together (Figure 4). Soil beneath the foundatiom must meet minimum bearing capacity requirements. When assembly cages and temporary bridge beams are in place, the contractor can proceed to railway track reconstruction. The structure should undergo a live load field test.

The adjacent track can be disassembled and the contractor can proceed with excavation and foundation works. After assembling the whole steel structure contractor proceeds with backfilling and restoring the disassembled track. When works are finished, traffic is diverted to the other track and the temporary bridge structure can be disassembled. The final step involves restoring the railway track.

2.3. Concrete filling

One of the common methods used for railway infrastructure modernization is concrete filling. This repair method is widely used especially for culverts and small bridges when either rebuilding cost is very expensive or short delivery time is required. If only site conditions and cross section parameters allow for incorporation of a steel structure then the entire construction process is simple. Before assembling the structure the contractor must prepare the foundation.

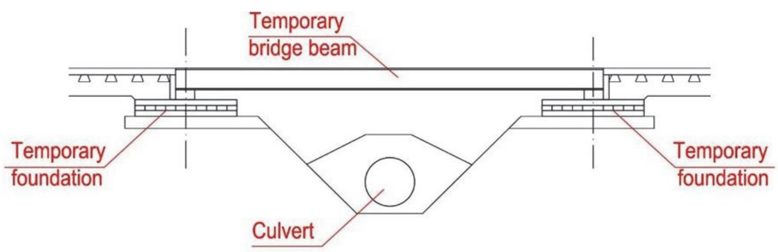

Figure 4. Longitudinal section of temporary bridge beams

When the structure is already assembled and in place it is very important to fill the space between the old construction and the CSS with low or high strength concrete or another similar material. If the new structure structure is to be longer than the existing one then both the outlet and the inlet is backfilled with soil.

3. LIVE LOAD TEST

3.1. Subject

A newly built railway structure on line E59 in km 152+900 (Figure 5) was subjected to a static live load test. The requirement to perform a load test results from internal regulations of the Railway Administration.

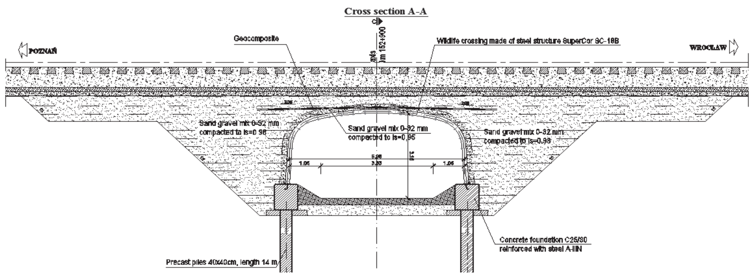

Figure 5. Cross section of the structure on line E59 in km 152+900

3.2. Structure parameters

- Top length: 16.84 m
- Bottom length: 24.05 m
- Steel profile: SC-18B
- Steel profile span: 5.96 m
- Steel profile height: 2.65 m
- Foundations: deep foundation
- Height of cover from bottom of sleeper: 1.32 m

3.3. Load test procedure

The static live load test of the railway structure under railway line E59 in km 152+900 was performed on 28.04.2016. The test was performed in daylight conditions, at a temperature of 14°C, with very good weather conditions.

Crown and foundations displacement readings were executed simultaneously with loading. Measurements were taken every 15 minutes until displacement stabilized. The last reading was made after 45 minutes and was accepted as the final result. Due to the live load test the structure was under observation to ensure that there were no cracks or excessive displacements. During the study, there no damage was noticed.

3.4. Load

A 118 ton ST-44 locomotive was used as live load (Figure 6). Measurements were taken by means of mechanical and precise leveling instruments according to the test procedure PB-01 [8].

Vertical displacements were measured by means of mechanical instruments with a range up to 50mm and accuracy of 0.01mm. Settlements of foundations were measured by optical precise leveling instruments with accuracy of 0.1mm. Position of load and measure instruments are shown in the drawing below.

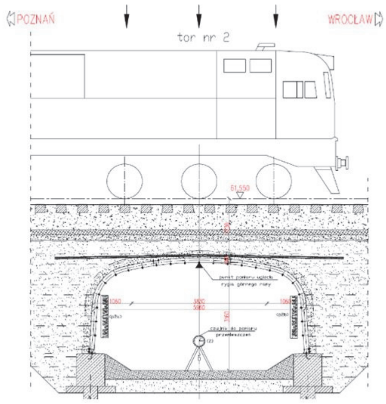

Figure 6. Cross section of tested structure. Load ST-44 locomotive

4. COMPARISON OF LIVE LOAD RESULTS WITH FINITE ELEMENT METHOD

4.1. FEM Model

A numerical model of the structure was prepared using Plaxis 2D software based on the finite element method (FEM) (Figure 7).

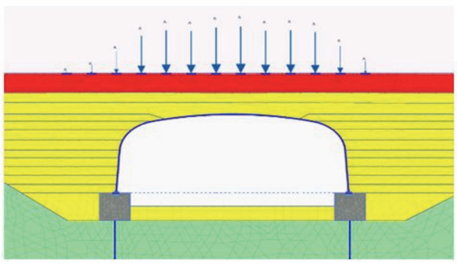

Figure 7. Numerical model of the structure

- Live load
  Redistribution of the load of the ST-44 on sleepers was made using Winkler's beam on elastic foundation theory. It was assumed that the modulus of subgrade C=40 MPa/m and the flexible stiffness of the rail is taken into account. Load reduction in the longitudinal direction by redistribution of stresses through the cover at an angle of 60 degrees was also applied.
- Soil model
  Backfill soil elements were modeled using Nonlinear Hardening soil model. This model makes it possible to take into account changes in soil modulus as a dependent of overburden pressure.
  Two models were prepared to verify the effect of foundation settling on crown deflection. Calculations were made for non-deformable and deformable subsoil.
- Technical parameters of backfill:
  E_{50}=45 MPa
  E_{ur}=120 MPa
  friction angle=38 degree
  weight=20 kN/m3
- Steel plate parameters
  Plate thickness: 7 mm
  EI= 4379 kNm^2/m
  EA=1773000 kN/m

4.2. Results comparison and conclusions

	Model 1 Deformable subsoil	Model 2 Non-deformable subsoil	Load test
Vertical deflection of crown [mm]	3.92	3.65	2.27
Settling of foundation [mm]	0.39	0.00	0.60
Ratio FEM/Load test [-]	1.73	1.61	–

There are no significant differences between model 1 and model 2. It can be noticed that the difference between the load test and the FEM model is 61-73 % which allows one to assume that the 2D FEM model yields rather conservative results for structures with a relatively shallow cover. There can be a number of reasons for that. One of them might be unrealistic load reduction in the longitudinal direction or assumption that there is no cooperation between rings. Other reasons could be improperly assumed backfill modulus. The aforementioned issues could be resolved by:

- using software based on 3D finite element method or application of a more sophisticated approach to load redistribution (reduction) in the longitudinal direction,
- taking into account cooperation between rings,
- making triaxial test of in-situ backfill material to provide realistic material parameters.

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