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Road bridge reconstruction design analysis

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Abstract: This paper presents a case study entailing the reconstruction of a road bridge. The original timber construction low-level bridge with rolled steel girders had lost its performance parameters due to biological corrosion of the structural timbers. The support piles were defective. The structure was taken out of use and a solution was proposed in the form of a composite span structure founded on prefabricated reinforced concrete piles. It is important to pay attention to the economic considerations of the reconstruction, as managers of lower category roads often only have a rather limited budget.

Keywords: road bridges, composite bridges, prefabricated elements, technical condition of bridges.

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1. Introduction

An important aspect in ensuring the safe operation of bridges is to perform a proper assessment of their technical condition, in accordance with the requirements set forth in the Construction Law [1] as well as in other specific regulations [2]. For low-level timber bridges with steel girders, it is often not the stress level that determines their durability, but the durability of the material used for timber piers and supports [3]. When it comes to fixed bridges the service life of a structure depends on the level of design, workmanship quality as well as the level of maintenance works [4]. This paper presents an example of a reconstruction of a low-level steel and timber structure road bridge. The aim of the publication is to identify an economical structural solution for the construction of a fixed road bridge. The presented design solution can be the basis for the construction of bridge crossings on similar crossings where a complete reconstruction of both the span structure and the support system is required.

The crossing comprising the subject-matter of this article is located on the Bzura River in the town of Klewków, Łowicz commune. Before replacement, the static system of the structure comprised four simply supported bays. The load-bearing structure of the bridge consisted of four girders made of rolled steel I-beams, braced using rolled channel cross beams. The outermost supports (abutments) were made as massive reinforced concrete structures, while the intermediate ones were made as spatial timber pile supports. The timber bridge supported by a steel grate was constructed as a transverse deck with a longitudinal auxiliary deck. The structure of the old bridge is shown in Fig. 1.

Fig. 1. View of the crossing over the Bzura river in Klewków before modernisation (author's work).

In the first place, a detailed technical condition assessment, consisting of an analysis of the load bearing structure and support system was carried out for the existing low-level structure. According to the said assessment, the bank supports, and intermediate supports were defective, the supports did not have adequate load bearing capacity and spatial rigidity. The bridge support system had to be completely replaced, which also involved rebuilding of the span structure.

Given the extent of the required repair works, a decision to build a new bridge was made. A proposal was put forward to build the bridge in a three-span continuous beam system, with a steel-concrete composite span structure. The support system was designed in the form of prefabricated reinforced concrete piles.

2. Technical condition of the bridge

Cross beams were used to brace the main girders of the structure to each other. Their condition could be described as satisfactory, i.e., the identified damage only reduced the aesthetics (localised general corrosion) but did not cause a reduction to operating parameters. A view of the steel bridge structure is shown in Figure 2.

Fig. 2. View of the steel bridge structure (author’s work).

In the analysis of the technical condition of the supports, attention should be paid to the classification of their damage. Damage to supports directly affects the load-bearing capacity and safety of a crossing and, as it progresses, the structure in question may even be taken out of use.

A lot of damage reducing load-bearing capacity could be observed on the massive abutments of the structure in question. The most noteworthy damage included diagonal cracks running across a considerable section of the abutment body, testifying to the poor condition and improper operation of the foundations. In addition, there was significant loss of material and thin vertical cracks indicative of reinforcement corrosion. An example of the condition of one of the bank supports is shown in Figure 3. In general, the technical condition of the abutments has been described as precarious.

Fig. 3. View of the damage to the reinforced concrete wall of the abutment (author's work).

The spatial intermediate supports were in the worst technical condition out of all the bridge elements. They were assessed to be defective, which led to the structure being taken out of use. The supports made of timber piles had corrosion damage to the extent that they were almost completely destroyed - Figure 4. In many instances, the piles suffered buckling due to large cavities, which clearly reduced pile diameters thus reducing their load bearing capacity. The greatest damage occurred at the fluctuating water table level. This damage, together with the poor condition of the timber, it meant that their load-bearing capacity was reduced to almost nothing.

Fig. 4. View of the damage to the intermediate supports (author's work).

Fig. 5 shows the extensive damage to the timber bridge caps and the horizontal and diagonal bracing of the intermediate supports. As the steel superstructure of the bridge is supported by the bridge caps, such extensive damage (decay, rot and cavities) has resulted in a virtually complete loss of load bearing capacity, both in terms of compression and bending. Pile bracing was broken and had large cavities, and in this condition the bracing did not fulfil its role of providing stiffness to the supports.

Fig. 5. View of the damage to intermediate support braces (author's work).

Pursuant to an assessment of bank and intermediate supports, carried out in accordance with the bridge assessment system (tab.1) set forth in the "*Instruction for carrying out inspections of road engineering structures, Appendix to Resolution No. 14 of the General Director of National Roads and Motorways of 7 July 2005"* [2], the structure was determined to be defective. A solution entailing a complete replacement of the bridge structure with a new one with a load-bearing capacity in line with today's standards was proposed.

3. Structural layout of the new structure

3.1. Design for the new bridge.

The new bridge was designed as a three-span structure with an overall length of 31.00 m, an overall width of 6.5 m and a 6.00 m wide roadway. The net horizontal clear span of the bridge is 28.20 m, while the vertical clear span of the bridge is 4.30 m in relation to the mean high-water level. The bridge is designed for vehicles with gross weight not exceeding 20 tonnes. Figure 6 depicts a longitudinal section of the bridge.

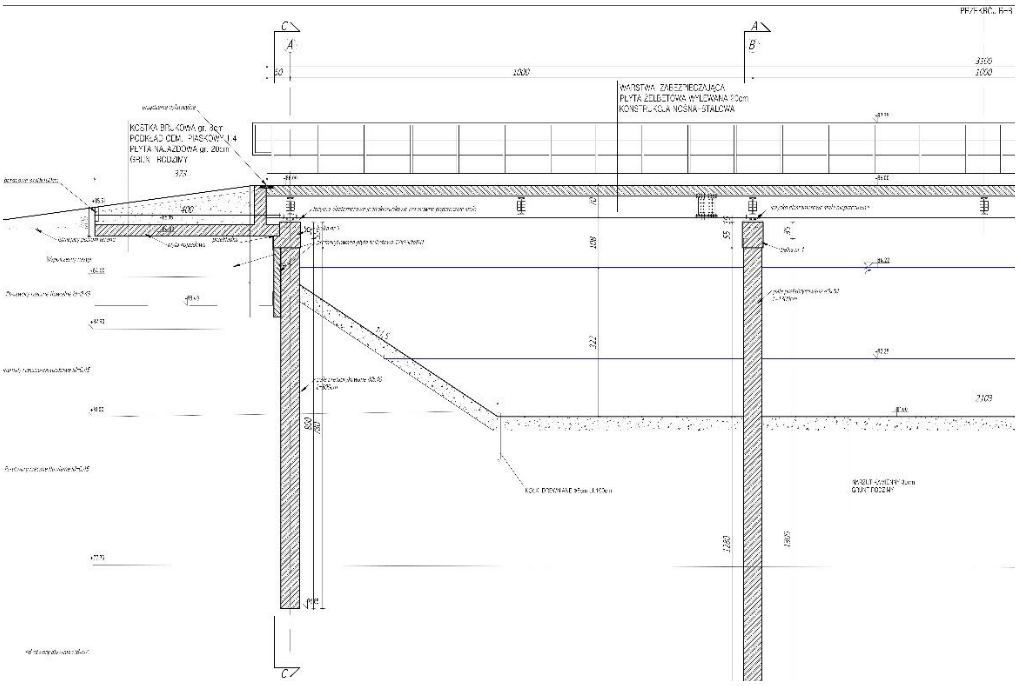

Fig. 6. Bridge longitudinal section [5].

The load-bearing structure comprises IPN500 steel I-beams supporting a reinforced concrete slab. A cross-section shows 5 girders with an axial distance of 1.37 m. Each bridge girder is made of three beams (two 9.50 m long outermost beams and one 12.00 m long central beam). 1.35 m long IPE350 steel I-beams make up the cross beams. The girders and cross beams were made of S355 steel. The layout and joints of the girders and cross beams are shown in Figure 7.

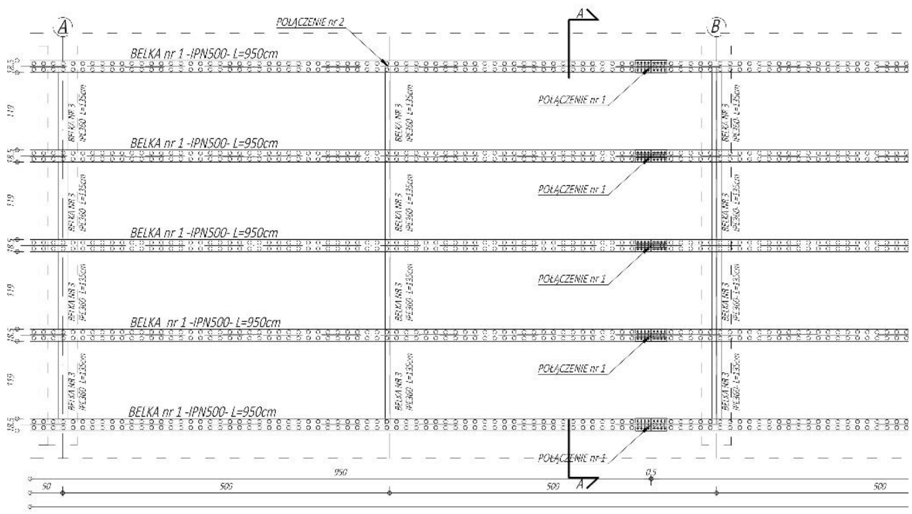

Fig. 7. Layout of girders and cross beams [5].

The 20 cm thick bridge deck is made of C 30/37 concrete and reinforced with AIIIN RB500 steel bars. The span structural height is 0.75 m. Figure 8 depicts a cross-section of the bridge bank support.

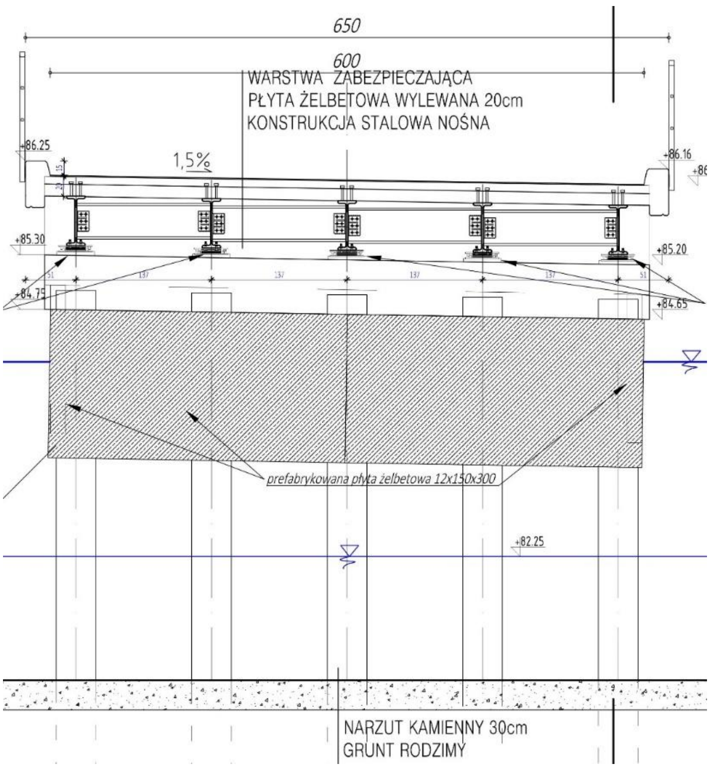

Fig. 8. Bridge cross-section (bank support) [5].

The supports comprise prefabricated reinforced concrete piles, 5 per support (Figure 8) with a 40 x 40 cm cross-section and a span of 1.37 m. The piles in the intermediate supports are 13.00 m long, while bank support piles are 8.00 m long (Figure 6). On the upstream side, the supports were protected with starlings (Figure 9). Figure 10 shows the new bridge.

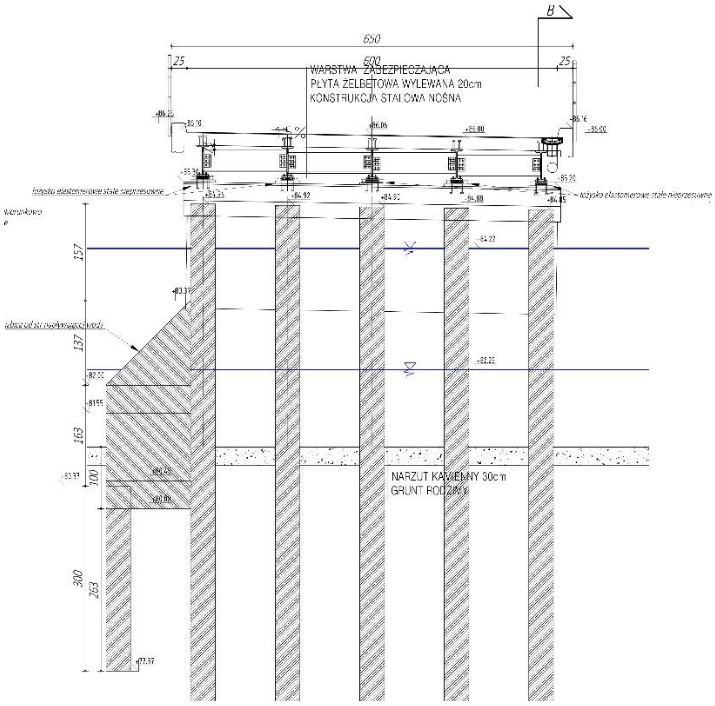

Fig. 9. Cross section of bridge intermediate support with starlings on the upstream side [5].

Fig. 10. View of the new bridge (author’s own photograph).

3.2. Construction of the new bridge

The new bridge is located next to the old crossing. Its location is shown in Figure 11.

Fig. 11. Axis of the new bridge relative to the old crossing [6].

Construction works on the new bridge included the dismantling of the old span structure and supports. First the timber railings and the timber elements of the bridge were removed, then the steel girders and cross beams. Then the intermediate supports were removed, and the reinforced concrete walls of the abutments were demolished. The cost of the entire demolition, including removal of scrap metal and rubble, was estimated at approximately 115,000 PLN (data based on the investor's cost estimate).

Works were being carried out on constructing the supports at the same time as the demolition. This included sheet piling, formation and compaction of earth dam embankments, driving of reinforced concrete piles, construction of starlings, construction of caps, construction of retaining walls, transport services and installation of bearings. According to the investor's cost estimate, all the activities associated with the construction of the supports are worth 370 thousand PLN. Figure 12 shows a view of driven the piles and their layout in intermediate supports. Whereas Figure 13 shows a view of the bank support and a retaining wall.

Fig. 12. Construction of intermediate pile supports [6].

Fig. 13. View of a bank support with a retaining wall [6].

Tasks associated with the strengthening and regulation of the watercourse were carried out within the scope of the new bridge construction works. These included construction of drainage ditches and channels, formation and compaction of earth dam embankments and strengthening of the riverbed and slopes. According to the investor's cost estimate, these works costs were estimated at around PLN 215,000.

Assembly of the bridge deck and its structure included the following works: transport services related to the delivery of deck elements to the construction site, loading and unloading, assembly of girders and cross beams, putting the entire structure together, construction of the bridge deck and supports, construction of drainage elements and assembly of bridge railings. Girders were seated on pre-set bearings. Elastomer single direction slide laterally fixed bearings were used on three supports and elastomer fixed non-sliding bearings on one support (B axis). Riveted joints of the end beams and the centre beam are shown in Figure 14. 20 mm diameter pin connectors with 150 mm spacing were used to connect the deck to the girders. The deck was reinforced with 12 mm diameter steel bars (AIIIN RB500 steel). Figure 15a shows a view of the roadway. Figure 15 b shows railing attachment method. The cost of the bridge was estimated at approximately PLN 686 thousand [8].

Fig. 14. View of the entire bridge with visible beam connections in the girder [7].

a) b)

Fig. 15. View of the bridge: a) roadway, b) railings (author's work).

The final stage of the project entailed joining the crossing to the accesses roads by constructing new ramps (Figure 16) and repairing the access roads. The estimated cost of this undertaking, including surveying services, was approximately PLN 52,000. The total cost of constructing the new bridge including demolition works was specified in the investor's cost estimate [8] at approximately 1,770,000 PLN.

Fig. 16. Constructing the ramps [5].

In 2016, a tender was issued for the construction of a new steel-concrete composite bridge and the demolition of the old steel and timber bridge. The tender resulted in the investment costing approximately PLN 900 thousand [8], which constituted about 50% of the assumed costs in the investor's cost estimate.

4. Conclusions

This paper presents an example of a reconstruction of a four span steel and timber structure road bridge. The aim of the paper was to identify a low-cost solution for retrofitting a fixed road bridge, which could be used for other engineering structures requiring a complete reconstruction. A justification for rebuilding the crossing is laid out in the first part of the paper. A technical assessment of the old bridge, consisting of an analysis of the load bearing structure and support system was carried out. According to the said assessment, the bank supports, and intermediate supports were defective. A decision is often made to build a new bridge due to the scope and cost of the required repair works [9, 10]. The main part of the article describes the design concept for a new span structure and a system of intermediate and bank supports. A proposal for a three-span bridge with composite steel and concrete span structure is put forth. Prefabricated reinforced concrete piles were adopted for the support system. Reinforced concrete starlings were added to strengthen the outermost piles of intermediate supports on the upstream side. The assumed cost of the investment in the investor's cost estimate was approximately PLN 1.77 million. As a result of the tender, the entire undertaking was completed for approximately PLN 0.90 million. The difference primarily stemmed from the use of prefabricated support elements and a composite span structure on precast rolled girders supporting a reinforced concrete deck.

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