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WIDENING AND STRENGTHENING OF A TWO-SPAN ARCH BRIDGE

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Abstract: *A two-span arch bridge was built in around 1920 over the Rega River in the centre of a small town. It is now located on a busy street in the old town and is the only river crossing in the town and vicinity. Over the years the requirements with regard to the bridge have changed due to the increasing volume of traffic and industrial transports. The bridge was designated for strengthening and widening with the introduction of wider sidewalks. The existing arch spans were used as support for a new widened reinforced concrete overslab. Reinforcement bars with shotcrete at the bottom of the arch spans were also added. The new concrete overslab was made continuous over the supports so the bridge was kept integral. For economic reasons, the bridge was rebuilt in stages without a temporary bridge. The form of the arches was preserved and new massive parapets modelled on the old ones were added to the wider deck. The paper describes the upgrading method which enabled the widening and strengthening of the existing two-span concrete arch bridge. New concrete with grade 500 reinforcement was used as the "outer" part of the spans. Keeping the bridge integral lowers maintenance costs. Modernisation of the drainage system protects the river water from traffic pollution. The bridge was rebuilt in stages, taking into account a nearby small hydroelectricity plant. Externally-attached utilities which spoiled the bridge's appearance were relocated under the riverbed. The paper describes the bridge works which were developed for improving the safety of the town's inhabitants and car users, both on local and transition routes.*

1 INTRODUCTION

The construction of concrete structures began with development of modern Portland cement. In the Szczecin region, where the upgraded bridge is located, the first cement plant was opened in 1853 [4], which soon led to the construction of concrete structures and products. The first structure used plain concrete and the next reinforced concrete [4, 7].
Bridges constructed several decades ago have deck widths and load bearing capacities adjusted to past requirements. Urban bridges built at the beginning of the twentieth century were designed to carry pedestrians and rare vehicles, usually horse-drawn. The carriageways were sufficient for shared use by pedestrians, so the sidewalks were narrow. The requirements with regard to urban bridge structures have changed several times over the last few decades. Increases in traffic and lorry weight are significant: on several roads, even of lower classes, very heavy lorries are now present. However, pedestrians are still important bridge users in urban areas.
The paper presents the widening and upgrading of an older concrete arch bridge. The bridge had been assessed to be substandard due to capacity needs and requirements for pedestrian sidewalk widths. Because heavy goods vehicles had appeared on the county road, there was a danger of accidents on such a bridge with narrow sidewalks. The proposal to replace the bridge by a culvert was rejected by the water authority and owner of a nearby small hydroelectricity plant. Another concept to repair the bridge without widening was rejected by the county road agency as not meeting demands. The author prepared a separate concept for renovation and widening of the bridge which was accepted by all parties.

2 THE BRIDGE BEFORE REBUILDING

It is estimated that the bridge was constructed in around 1920 as two-span arch with a 5.7 m carriageway and sidewalks of narrow widths. The total width of the bridge was 8.85 m (Figure 1). The overall length was 39.3 m. The bridge is located over the Rega River along a busy street in the old town. The street also serves as a county road of regional importance. At the time of construction, the width of the deck and sidewalks were quite sufficient for demand. The superstructure was a two-span arch cast "in-situ" with clear spans 2×16.10 m at the springing line.

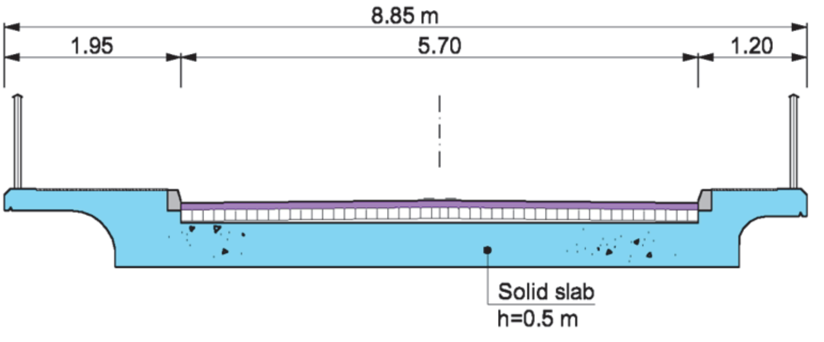

Figure 1: Cross section at the crown (as built)

Figure 2: General views of the bridge with the historic hydroelectricity plant

The river flow is dammed before the bridge for hydroelectricity plant purposes and the clear bridge span is usually smaller. The rise of the arch was f = 1.9 m and the span length L = 17.0 m, giving a ratio of span to rise L/f = 9. The concrete arch barrels were 0.5 m thick at the crown. The barrel soffits were reinforced with structural steel angles: two angles of L50×50×5 mm (leg back to back) at spacing 0.6 m. The angles have riveted joints. Structural steel reinforcement gave the minimum reinforcement ratio for the barrels (0.14% at the crown section) but the concrete cover was carbonated. Due to leakage, the concrete cover had deteriorated locally and some patch repairs had been carried out.
The sidewalks were on reinforced concrete cantilevers and were protected with riveted steel balustrades with concrete wall sections. The support walls are of plain concrete on timber piling. Side views of the bridge before rebuilding are shown in Figure 2. The view of the arches was spoiled by externally-attached utilities (water and sewage).
Originally the carriageway used stone block pavement but when the number of cars increased, a bituminous wearing course was added. The concrete barrel surfaces had been repaired due to the spalling of the concrete. The bridge needed upgrading, as it is also located along an industrial transport route from a timber processing plant on the outskirts of the town. The bridge is the only such structure over the Rega River in this region. The design load class used at its construction was much lower than that presently required for existing bridges (40 t). The fittings and concrete surfaces were in poor condition; however, checks on the concrete quality and strength gave satisfactory results. No traces were noted of insufficient capacity in the structure; however, some war damage had been covered. The bridge drainage systems were insufficient. Waterproofing was nonexistent and there was leakage on the barrel soffits. Over the years, municipal utilities had been added externally to the bridge sidewalk cantilever (Figure 2) and these needed to be removed.

3 UPGRADING REQUIREMENTS

The bridge did not meet safety requirements and had been designated for widening and upgrading. As with all older bridges, there are some uncertainties regarding technical conditions and capacity. No survey of the bridge capacity had been performed before commencement of the final rebuilding project. There were no other bridges for heavy goods vehicles in the town and nearby, so long traffic diversions would be expected in the case of bridge replacement or a temporary bridge. For the rebuilding of the bridge, general requirements were drawn up:

· the minimum loading class for existing bridges on county roads;
· compulsory adequate sidewalks;
· safety barriers;
· no utilities on the bridge (sewage and water);
· full administrative procedure for the project;
· no temporary bridge (lower project costs).

The first requirements deal with structural and safety considerations but the last was for economic reasons, since the county road authority simply could not afford a temporary bridge. All the evaluation and planning principles found in transportation infrastructure were followed in the bridge upgrade design. Firstly, a survey of the bridge's structure, materials and existing utilities was carried out. The soil conditions were also evaluated and weak soils were found which are not conducive for arch bridges. The superstructure concrete was assessed to be non-uniform but in areas of good condition an average grade of C28/35 was assessed. There was leakage through the concrete arches and spalling of the concrete was found on the soffits of the barrels. Some patch repairs of poor quality were noted. The surfaces of the arches and supports were uneven and rough. Steel angles with riveted joints were found at the arch soffits but they were corroded with spalling concrete. In the structural analysis, the simple arch model method was developed and for live loads the strip method was used. The calculations gave highly satisfactory results and hidden strength was found in the arches.

The bridge arches and supports would have to be widened, repaired and adjusted to current demands. In addition to the structural aspects, sustainability issues needed to be addressed [1]. Verification of the foundations was more uncertain and cement grout injections were assumed for strengthening the weak soils. The bridge was verified according to Polish bridge standards using elastic section analysis. While preparing the renovation plan for the bridge, it was assumed that the arches would be kept integral with the abutments for better structural behaviour and lower maintenance costs.

4 UPGRADING DESIGN

The introduction of heavy goods lorries onto the bridge caused safety problems both in terms of traffic and pedestrians. Following verification of the arch concrete conditions as well as the arch capacity, it was decided that the bridge should be strengthened and widened. The existing arch spans were used as supporting barrels for a new wider reinforced concrete overslab with transverse and longitudinal reinforcing rebars. Strengthening reinforcement mashes in shotcrete were also added to the soffits of the arch barrels. The new top concrete slab was made continuous with supports so no dilatation gaps were used in the structure. The overslab replaced the stone pavement and road base of the old structure and was made composite with the existing barrels by dowel rebars. After upgrading, the width of the bridge is 10.56 m and consists of a 6.0 m carriageway and two sidewalks with clear width of 1.5 and 2.5 m. The cross section of the bridge after upgrading is shown in Fig. 3. The design widths are consistent with the approaches. The bridge capacity has been increased to carry heavy lorries. New concrete with grade 500 reinforcement was used as the new parts of the structure. Keeping the bridge integral should lower the maintenance costs. Modernisation of the drainage system protects the river water from traffic pollution and secures the structure from damage due to leakage. The bridge was rebuilt in stages, taking into account a nearby small hydroelectricity plant.

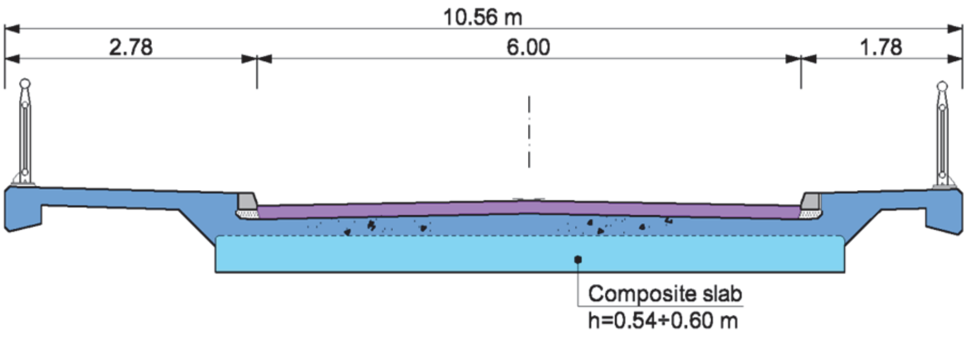

Figure 3: Cross section at crown after rebuilding

One lane was kept open to traffic. For the repair of the supports and barrel soffits the power plant was closed while the water level was lowered.

For a stronger and wider bridge, the existing arches were used as the bottom sections for a new wider RC overslab with side cantilevers. (Figures 3 and 4). For the overslab C32/40, concrete grade was used with cube strength $f_{ck,cube}$ = 40 MPa and high-yield reinforcement with tensile strength f_{yk} = 500 MPa. The general layout of the strengthening overslab is shown in Figure 4. The overslab is used to strengthen and protect the existing arch barrels as well as to widen the deck. The overslab replaced the road base and stone pavement in the old structure and was made composite with the existing arches. The wider overslab allowed wider sidewalks to be placed on overslab cantilevers. The new composite concrete arches have a higher structural depth and therefore higher resistance.

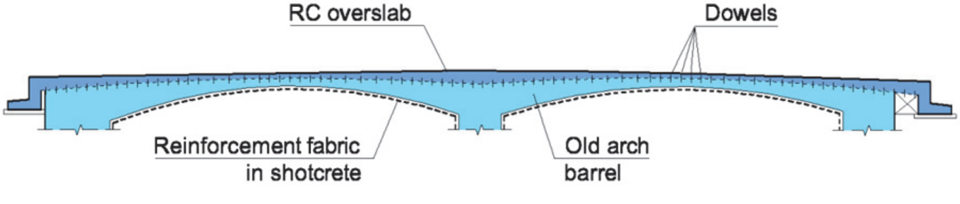

Figure 4: Longitudinal section through the arch superstructure with strengthening overslab

The existing bottom reinforcement (two angles spaced at 0.6 m) has sufficient strength but did not meet serviceability requirements. Rebar reinforcement in shotcrete was added. The vertical alignment of the street was raised over the internal pier by 0.1 m, rounded with a vertical curve and tapered to the approaches on two sides of the bridge. This meant that rebuilding the street pavement on longer sections could be avoided. The bridge capacity has been increased to 40-tonne vehicles which covers all vehicles from the Road Vehicle Regulations.

Transverse and longitudinal rebars were used as the strengthening reinforcement and, in addition, continuity reinforcement was designed over the pier and abutments. The overslab was designed as integral with the abutments which allowed the structure to remain without expansion joints and the possibility of leakage. For maintaining continuity behaviour, small

RC pads were introduced. The approach sections of the road were protected by small run-on slabs which were made continuous with the overslab (Figure 5). The road base was placed on the run-on slabs and no movement joints were used in the asphalt surfacing [2]. The overslab cantilevers were designed to be continuous on the barrels and on the wing walls. On the wing walls short cantilever overslabs were used under the sidewalks. Dilatation gaps with filler were used at the end of the bridge sidewalks. Keeping the arch bridge structure integral made it possible to avoid joint movement in the asphalt surfacing.

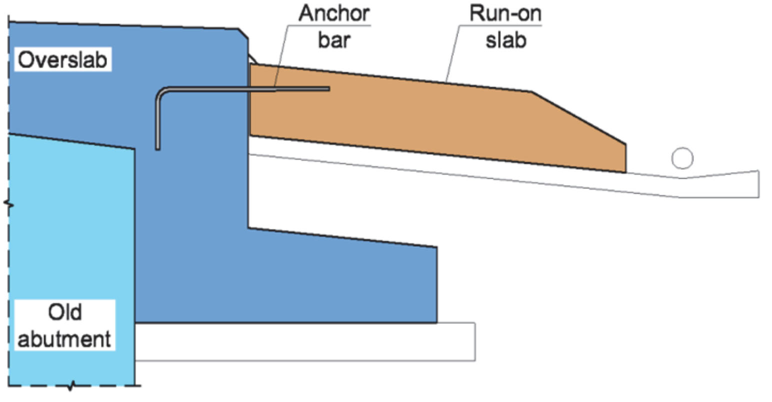

Figure 5: Longitudinal section through the end of superstructure and run-on slab

The design for the upgrading of the bridge allowed the old arch bridge span to be used as the supporting section of a new structure with larger resistance. New, external sections to the two-span arch bridge were constructed from structural concrete and shotcrete of grade C32/40. The concrete surfaces were cleaned, dowels and reinforcement rebars or fabrics were fixed and concrete was poured or shotcrete was sprayed. The weak soils under the support foundations were strengthened by injection of a cementitious grout. The upgrading design followed the general rules for repair of historic concrete and arch bridges [3, 5÷10].
The bridge had been poorly maintained for many years. Despite spalling and cover carbonation, the concrete in the arch barrels had performed quite well, still giving strength and support to the road carriageway. The rather good quality of the arch concrete gave the possibility of widening and upgrading the bridge.

5 FINAL BRIDGE WORKS

The bridge upgrading works required the closure of one lane to traffic. The execution of the bridge work in two stages was developed in the design. At the beginning of the works, the integrity of the concrete supports was verified and the soil under the foundations was strengthened by compound injections. The utilities attached under the upstream sidewalk were relaid under the riverbed. During the construction works, one lane for traffic and one sidewalk for pedestrians were permanently kept open. The general arrangement of the construction stages is shown in Figure 6.

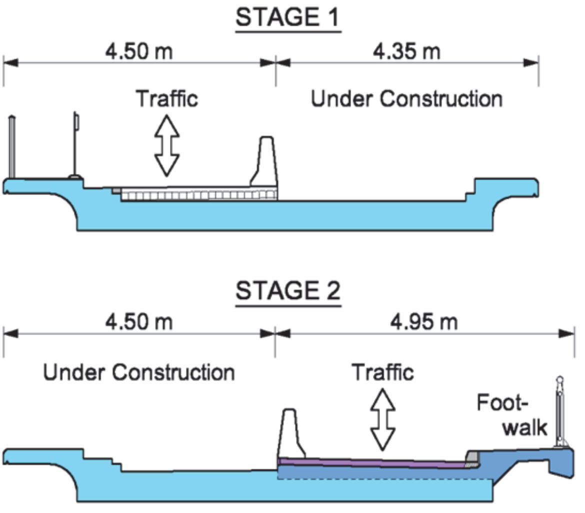

Figure 6: Construction stages for bridge upgrading

The bridge works followed the design schedule. During the demolition works, some major longitudinal cracks were found on the top of the arch barrels which were repaired. After the overslab construction, waterproofing and a bridge drainage system were installed.

The bridge deck was equipped with new wider sidewalks. The arch spans and supports were repaired and strengthened. During the earthworks, near the abutments, rectangular timber piles of deep foundations were discovered, which proved to be in very good condition. The general appearance of the bridge was improved by removing the external utilities and making a road restraint system in the form of old balustrades. The old gas lighting poles on the bridge parapets were renovated and electric lighting was installed. Views of the bridge after upgrading are shown in Figures 7 and 8.

Figure 7: The bridge at opening (2009)

Figure 8: After 3 years in service (2012)

6 CONCLUSIONS

The widening and upgrading of the bridge were carried out in 2009. After 3 years in service, no defects in the upgrading work have been observed and the bridge remains in very good condition. The overslabbing technique was used for the refurbishment of the arch barrel bridge structure. The new overslab replaced damaged RC side cantilevers and stone pavement on the bridge. The overslab allowed the bridge to be kept integral and no expansion joints were installed in the asphalt carriageway. Waterproofing was installed and all other damaged accessories were replaced. The overslab increased the bridge strength to current load demands and widened the deck for a wider carriageway and new sidewalks. Both bridge and user safety were significantly increased. The architectural view of the bridge was improved by removing externally-attached utilities and keeping the original arrangement of balustrades and bridge lighting.

Old bridges are usually presumed to have poor concrete, but some of them have performed surprisingly well. The bridge in this paper, in general due to the good performance of its structural concrete, was preserved and was rebuilt to give it a few more decades of service life. Despite the widening, the historical form and line of the arches were maintained. The works had no influence on the statutory listed hydroelectricity plant in the vicinity of the arch bridge.

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