RETROFITTING OF A MASONRY ARCH VIADUCT AND CULVERT

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SUMMARY

A masonry arch structure more than 100 years old required repairs and retrofitting. The structure consists of two brick barrel arches, one for a viaduct and the second for a culvert, between stone supports. Due to a very long period of service with low maintenance, some damage and cracks had appeared. To preserve the structural and architectural values of the masonry structure, it was decided to repair and strengthen it. A design was drafted for the rehabilitation of the structure while preserving its original form and appearance. Repairs were carried out, cracks sealed, bricks which had deteriorated were replaced, the spandrel walls at the crown and stone footings at the cracks were strengthened, the structure was cleaned and a protective coating applied. The originality and appearance of the structure were restored. The retrofitting was effective and economic, extending the arch structure's lifespan by several decades.

Keywords: *Railway bridge, railway culvert, masonry structure, repair and retrofitting.*

1. INTRODUCTION

Masonry railway bridges are a part of our engineering heritage. In the 19th century, the majority of railway bridge structures were constructed as masonry works. Brick barrel arches were the basic form of spans used to cross small obstacles, and continued to be used even at the beginning of the 20th century [1-3]. The structural, architectural and resistant advantages of arches determine their excellent performance and aesthetic values. Some of these arch structures have survived in reasonable condition up to the present day without requiring major repairs and with minimal maintenance. Today, they provide evidence of engineering craftsmanship and the development of bridge engineering, especially on the railways. These structures are now over 100 years old and they require conservation, repairs, retrofitting or replacement.

The repair and retrofitting of an existing masonry arch structure constructed in 1895 for the Piła and Ulikowo Railway in West Pomerania, Poland is described in the paper. The structure consists of two brick barrel arches, for a viaduct and for a culvert, between supports built entirely of stone masonry. The structure passes a non-electrified one-track regional railway line over a hill and a cart track to the "Dry Forest Hill" nature reserve. The height of the masonry structure is over 9 m over the hill level. The railway line was designated for retrofitting as part of a modernisation programme for the regional railways in West Pomerania. Another two truss bridge structures on the line which had deteriorated were also retrofitted and reopened to traffic.

The viaduct structure was in reasonable condition with small longitudinal cracking and small leakages in the spandrel areas at the crown. Wider cracks had formed at the midst of the brick barrel as elongations of cracks in the stone walls and foundations. The condition of the culvert structure, however, was much worse, with many cracks and crevices as well as deterioration in the brick masonry caused by water shedding from the damaged or overlooked drainage system. The main cracks and the crevices in the brick barrels and the stone supports were caused by uneven settlement on the substrata.

As regards the structural and architectural values of the structure, it was decided to carry out repair and retrofitting works which would preserve and restore the 19th-century engineering craftsmanship of the masons. The authors prepared a design concept for retrofitting the structure, taking into account the preservation of the original form and appearance. This was the basis for the design and execution of the retrofitting work. In the modernisation project, the main emphasis was put on the correct design of the drainage system as the chief element of durability in masonry structures.

The retrofitting of the masonry railway structure consisted of the viaduct and the culvert and was executed as part of a modernisation programme on the regional railway lines in West Pomerania, Poland. The design of simple methods for the repair and strengthening of the structure allowed its original form to be preserved without changing its appearance. The masonry bridge structure elevations were preserved and restored as the main component of the architecture and its attractiveness. The main focus was on the careful detailing of the drainage system as the base for the longevity and durability of the masonry work. The retrofitting has prolonged the structure's service life for the decades to come.

2. THE STRUCTURE BEFORE RETROFITT

The bridge structure was constructed in 1895 as one of the engineering structures for the current Piła and Ulikowo Railway Line. The masonry structure was constructed as two-span with brick barrel arches for the viaduct and the culvert. The supports and wings were constructed from stone blocks (Fig. 1). The culvert was constructed to take the water flow from the hillside where the railway line embankment is situated.

The width of the viaduct is 11.0 m with the length 5.30 m (Fig. 2). The clear span of the viaduct is 5.0 m. The road under the viaduct allows access to a forest nature reserve and an old burial site. The total length of the culvert, located alongside the viaduct support, is 26.0 m. The culvert clearances are 1.5 m (horizontal) and 2.1 m (vertical), respectively. The bottom of the culvert is stone faced (Fig. 1 & 3). The culvert is bent in plan.

The brick barrel arches of the structure are circular in shape. The viaduct barrel has an intrados radius R = 2.5 m; the barrel width is 10.92 m. The barrel thickness is 0.64 m. Two types of clayed bricks are used in the barrel structure. In the main part of the barrel, brick with dimensions 250 × 120 × 65 mm is used. For the external parts of the barrel, brick of 240 × 110 × 65 mm is used. The spandrel walls are stone masonry with concrete wall copings. The thickness of the culvert barrel is 0.38 m and brick of 250 × 120 × 65 mm is also used. The head and wing walls of the culvert are stone masonry with stone coping.

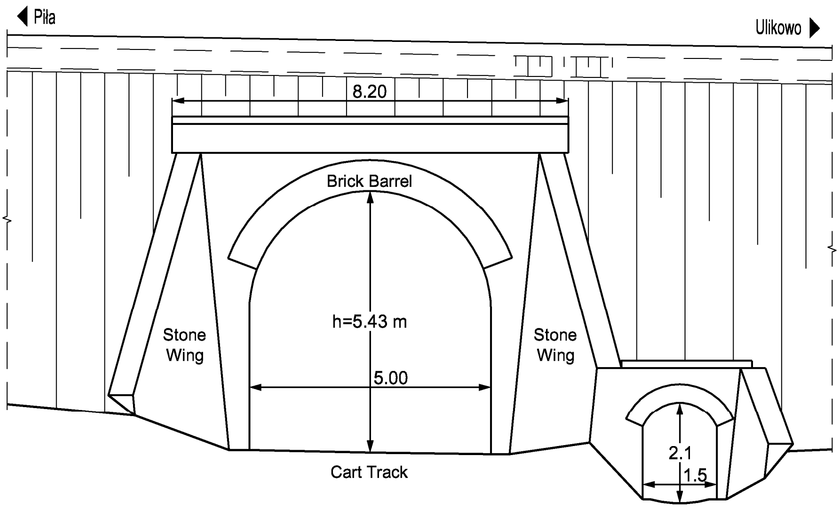

Fig. 1. North elevation of the masonry arch structure.

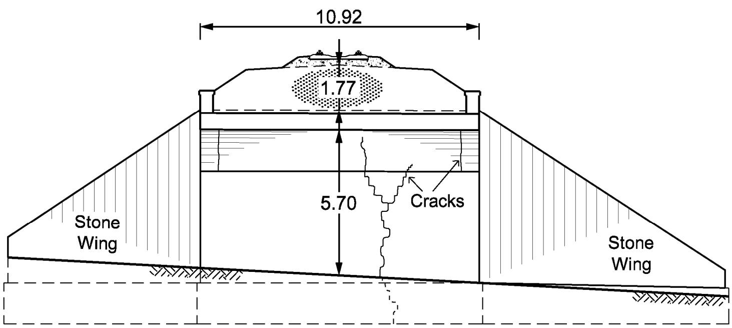

Fig. 2. Viaduct cross section.

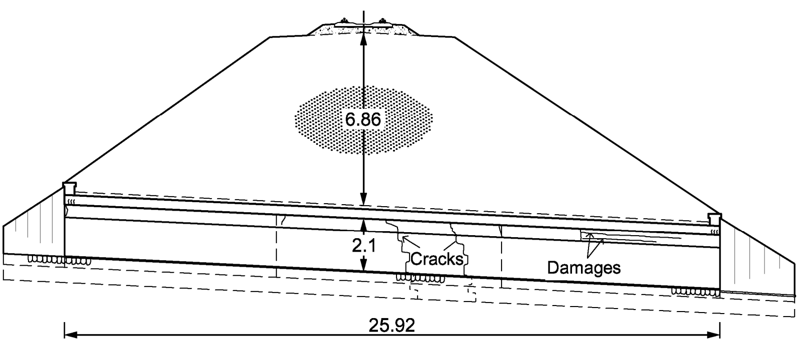

Fig. 3. Culvert longitudinal section.

Fig. 4. *Viaduct covered by foliage.*

Fig. 5. *Masonry culvert.*

The brick barrel arches are supported by wedge-shaped stones on stone walls at the springing. The support and wing walls are stone masonry from rectangular stone blocks and mortar joints. The sections of the structure are presented in Figs. 1 to 3, with the characteristic patterns of cracks and crevices generally visible. General views of the viaduct and the culvert (conduit) before retrofitting are shown in Figs. 4 and 5, with excessive vegetation flourishing near the structure.

Standard rail sections S49 on concrete sleepers embedded in ballast were used in the track structure. The railway embankment slopes were poorly maintained and were covered by uncontrolled self-sown plants (Fig. 4). A section of the railway line had been closed to traffic due to the poor condition of the two truss bridges and the track structure.

3. DETERIORATION, CRACKS, LEAKAGE AND DAMAGES

There were characteristic fine cracks in the viaduct barrel beneath the spandrels, which were wider at the crown. The width of the cracks at the crown was 2-3 mm beneath the north spandrel and 1-2 mm beneath the south spandrel (Fig. 2). There was also leakage on the external parts of the brick barrel. In the middle section of the barrel arch there were small cracks issuing from the wider cracks in the supports and foundations. However, the general condition of the viaduct was surprisingly good, given its long life. Cracks in the edge sections of railway barrel arches can very often be found due to transversal deflection of the spandrels [1, 4-6]. The cracks in the middle section of the barrel arch were evidence of uneven settlement on stiff clay and clayed sand substrata. At the crack location a humid plastic clay was found in the strata. The crevices in the stone walls of the supports were along the vertical and horizontal mortar joints. The crevices in the wall joints led to crushed stone foundations and were wider at the bottom.

Damage to the culvert structure were more severe, with wider crevices in the stone wall at the settlement, and crevices and cracks in the culvert barrel arch. At the location of water shedding from the viaduct side, there was excessive leakage and dampening of the masonry walls and the barrel arch, which had resulted in the destruction of the mortar joint and brick material. The stone wall was stained by calcareous leakage. Damage to the brick parts had also appeared on the head parts of the culvert made by the water shedding on the embankment slopes. Excessive damage occurred on the end section of the culvert conduit of 5.5 m in length where water was shedding extensively from the viaduct. Crevices in the side stone walls of the culvert also in evidence through the mortar joints. The stone surfacing of the culvert bottom was found to be in very good condition.

4. THE STRUCTURE RETROFIT

The railway line and the masonry structure had been in service for many years with very low levels of maintenance. This segment of the railway line was still open to traffic but the last segment had been closed due to the poor condition of the two truss bridges and the track structure [2]. The whole Wałcz and Ulikowo Railway Line was designated for retrofitting and the railway connection between Szczecin and Wałcz was re-established. The masonry structure and the two non-operated truss bridges were modernised and their structures were repaired, their technical parameters and load bearing capacities were restored. The good condition of the masonry materials allowed the structure to be refurbished rather than replaced but severe local damage to the culvert brick barrel required repair by replacement. Due to its age, cleaning and removing vegetation from the structure were undertaken. Sand blasting was necessary to clean off the dirt and stained surfaces, and check the condition of the materials.

The retrofit of the masonry arch viaduct and culvert assumed the protection of the barrel arches against water with the construction of a new drainage system, injections into the cracks and crevices, strengthening of the connection between the barrel arches and the spandrels at the crowns, local strengthening of the stone walls and foundations, replacement of the deteriorated bricks, brick masonry repair, repair of the mortar joints with repointing, sand blasting of the structure surfaces and the application of penetrant and protective coatings. All the members and embankment slopes were cleared of vegetation. Railings on the viaduct were added and the stairs on the slope were repaired.

The load bearing capacity of the structure was verified. Idealised arch models were studied without any correction coefficients [4]. The effects of backfill and formation level on the distribution of loads were taken into account. Resistance was assessed using simple numerical models for traffic action according to EN 1991-2 e.g. a UIC Load Model 71 with the factor $\alpha = 1.21$.

The simplicity of the arch structure along with its structural and aesthetic values allowed a typical range of repair and retrofitting works to be drafted which do not influence the appearance and the behaviour of the structure to a large extent. The repair works and local strengthening have not altered the elevations and structural behaviour. The culvert structure was preserved after the repair and replacement of the deteriorated masonry and strengthening despite an accepted proposal to line it with a corrugated steel pipe. The head walls of the culvert were rebuilt using the same stones and plates. They were also protected from water shedding from the slopes, and precast gutters were installed.

Great effort was put into installing a sufficient drainage system to collect water from the ballast and protect the masonry structure. A geo-membrane with geotextile protections and a drain set were designed in the subgrade to take the water. A geotextile membrane with sufficient slope was placed under the blanket of the trackage.

Fig. 6. *North elevation of the masonry arch structure after retrofitting*

***Fig.** 7. Detail of a crack in barrel arch.*

***Fig. 8.** Cracks after repair.*

General views of the viaduct and the culvert during the finishing works are shown in Fig. 6. Figures 7 and 8 present the longitudinal cracks in the viaduct brick barrel before and after repair. The brick masonry is very sound despite the cracking.

Fig. 9. *Stone wing before cleaning and repair.*

Fig. 10. *Stone wing after cleaning and repair.*

Fig. 9 and Fig. 10 show the technical condition of the stone wing before and after cleaning and repair. In the masonry wings vegetation had been allowed to thrive, which had resulted in some uncertainty about their soundness. After cleaning and repointing they appeared to be very sound.

To prevent a repeat of the cracking and leakage of the brick barrels beneath the spandrels, their connections were strengthened at the crowns with reinforced concrete strips. The crevices in the stone footings were also secured with small reinforced concrete walls (patches) with anchors. For construction of the strengthening reinforced concrete members, self-compacting concrete was used. The cracked joints of the stone walls in the supports were strengthened by the installation of flat steel bars into the new joint mortar. It was estimated that such means of strengthening would be sufficient to prevent further development of cracking, in addition to not giving too much rigidity to the brittle masonry members susceptible to cracking and splitting.

5. CONCLUSIONS

Very few masonry arch bridges were regarded as functional structures and they had therefore been replaced with modern structures as a necessary investment. Some replacement structures built several decades ago are now in much worse condition than masonry arches which had not been replaced. The estimated durability of some modern types of bridge structure and their details appeared to be illusive. The long-term neglect of cleaning had changed the appearance of the bridge structure, resulting in an excess of vegetation, dirt and rubbish. Vegetation and leakage may endanger masonry structures if they are not maintained properly [5, 6].

It ought to be considered why an arch structure should be replaced when it is possible to refurbish it. The attitude to old bridges is slowly changing as arguments that new structures are more durable are not always confirmed. Taking into consideration sustainability issues, a retrofitted bridge is always cheaper than a new structure.

There are still many masonry arch bridge structures in service. Their structures are quite similar and even standard. Their actual condition depends on many parameters, but usually depends on the bridge-building materials used in their construction. The spandrels of arch structures are usually too weak to resist horizontal pressure behind them. The major threat for masonry structures is caused by ineffective or a lack of drainage systems. Part of the masonry bridges constructed at the end of the 19th century are still in satisfactory condition, providing evidence of the long-lasting durability of such structures. Masonry arch structures are architecturally and aesthetically pleasing, and are fine examples of the engineering craftsmanship of their builders. They possess extended durability and large capacity, but also some characteristic defects resulting in the cracking of the barrel arches underneath the spandrel walls [1-3, 5, 6]. While the era of masonry arch bridge construction has passed, there are still many structures in service awaiting conservation and repair.

The railway line and the masonry bridge structure had been in service for many years without maintenance and conservation and, as a result, some deterioration and cracks had appeared. Despite over 115 years in service, the main members were still in reasonable condition. As usual, the worst damage was caused by uncontrolled water ingress. In this case it was the culvert which had become damp due to water shedding from the viaduct. The masonry structure consisted of the viaduct and the culvert has a weak point associated with improper drainage at the connection of the two structures.

The retrofitting preserved the historic form and appearance of the masonry arch viaduct and culvert structure. As the bearing capacity was ensured, the main element of the retrofitting was the water shedding protection and the construction of an efficient drainage system. The retrofitting and conservation of the brick and stone masonry improved the structure's appearance.

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