Diagnostic and Analysis of Selected Masonry Railway Bridges on Slovak Railways

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Abstract. *The paper presents an overview of the current state of railway masonry arch bridges that are in operation on Slovak Railways. The material of the vault is either stone or brick. It also presents the current possibilities of diagnostics, monitoring and evaluation of failures, the method of measuring selected material characteristics of masonry elements (especially the determination of compressive strength). Within the cooperation of our department and the Research and Development Institute of ŽSR, applications of diagnostic measurements and evaluation of the current state of these bridges are presented on selected bridge structures.*

Keywords

Masonry arch bridges, Diagnostic, Maintenance, Destructive testing.

1. Introduction

Masonry arch bridges form an integral part of the railway structure. They are the oldest structure type of the railway bridge population, with thousands still in service despite their age and the significant changes in loading conditions that have occurred since their construction. Generally, these structures were designed using empirical rules considering contemporary railway loads, which has resulted in structures with an inherent ability to withstand the applied loads and extreme weathering conditions. Today many masonry arch bridges carry loads that are radically different from those that were applied when they were constructed.

The condition of masonry arch bridges can vary from as new to in need of urgent action, but nevertheless they have proven durability with life-cycle costs significantly lower than the majority of other structure types. Additionally, many masonry arches belong to the civil engineering heritage of the railways and maintenance policies for masonry arches should therefore require that careful consideration is given to options for their repair. Total replacement of deteriorated masonry arch bridges is generally unnecessary and expensive and should therefore only be considered in rare cases.

Maintenance strategies should promote solutions that preserve and restore arch structures, although repairs of a significantly deteriorated arch could be more expensive than replacement with a bridge in another form of construction, [1].

2. Masonry Arch Bridges in the Slovak Railway Network (ŽSR)

On ŽSR lines, we usually distinguish between steel bridges, which make up approximately 22% of the total number of bridges, and a large group of massive 78% bridges, in which we also include brick and stone bridges. There are 407 bridges over the age of 100 years, and among them we can find bridges from 1848 – these are the oldest bridges in Slovakia, which were built during the construction of the Central Hungarian Railway in 1840-1850. The most important bridges of this type include: Hanuš Viaduct, Chmaroš Viaduct, Telgárt Viaduct, Marchegg Viaduct.

The choice of material for the supporting structure of the bridge, especially for single-pole arch bridges, was conditioned by the availability of local resources and the time of track construction. The first railway lines in Slovakia, which were built in the years 1844-1850 (Central Hungarian Railway) preferred brick. The Hungarian-Galician Railway (1860-1873) and the Hungarian Northern Railway (1864-1873) again used stone for the vaults. Arched bridges made of plain or reinforced concrete can be found on the Košice-Buhumín Railway in sections that were built in the 1950s.

At the present (2022), we have in operation both the original and the reconstructed and reinforced masonry arch bridges, the extent of which resulted from failures or the current need to expand from a single-track to double-track system, or in connection with the modernization of ŽSR lines to the higher line speeds up to 160 kmh^{-1}.

Overview of selected masonry arch bridges in ŽSR lines:

- material of arch (vault): brick, stone
- Number of bridge: 60 – brick, 124 – stone.

Stone arch bridges are suitable for smaller spans and therefore the correct indicator is the span 4.0 m inclusive. According to this criterion, we have 70.16% of smaller stone arch bridges and 29.84% of large stone arch bridges. An important indicator is evaluation of the arch bridges in terms of their condition.

The degrees of evaluation of the technical condition of the load-bearing parts of bridges are determined according ŽSR TS 5 Administration of Bridge Structures, [2]. Within the masonry are bridges, the steps are reported separately for the vault and the substructure. The railway regulation introduced five levels of verbal assessment of the condition of bridges, culverts, railway scales and footbridges.

Tab.1: Evaluation of masonry arch bridges in terms of their condition: brick arch bridges.

Bridge condition [2]	Brick arch bridges	
	Vault [%]	Substructure [%]
Level 1 – excellent condition	13.33	33.33
Level 2 – good condition	56.67	36.67
Level 3 – satisfactory condition	16.67	28.33
Level 4 – restrictive condition	13.33	1.97
Level 5 – unsatisfactory condition	0	0

Tab.2: Evaluation of masonry arch bridges in terms of their condition: Stone arch bridges.

Bridge condition [2]	Stone arch bridges	
	Vault [%]	Substructure [%]
Level 1 – excellent condition	9.67	24.19
Level 2 – good condition	52.42	39.52
Level 3 – satisfactory condition	28.22	20.16
Level 4 – restrictive condition	9.69	16.13
Level 5 – unsatisfactory condition		0

Table 1 and 2 shows that approximately 14% of bridges are in level 4 and require a comprehensive reconstruction or replacement of worn parts. The technical condition of these bridges affects the safety and smoothness of railway traffic with an impact on in line speed and load-carrying capacity. About quarter of bridges have major defects that require repair beyond routine maintenance or replacement of some unsatisfactory parts. On half of the bridges, there are only visual defects, damage that does not affect the load-carrying capacity and operation on the railway line. Only 11% of bridges are without obvious or visible damage or after their comprehensive reconstruction or after the strengthening of the vault. [3]

3. Diagnosis and Faults of Arch Bridges

Diagnosis of these types of bridges is usually focused mainly on monitoring faults, deformations, measuring and monitoring cracks in joints or in masonry elements, obtaining current material characteristics. Destructive methods (taking of core cylindrical samples, followed by compressive strength tests on the samples taken in hydraulic press), semi-destructive tests (tear-off tests, Schmidt hammer strength tests (see Fig. 1) penetration tests) and non-destructive testing methods (ultrasound, radar, tomography, thermography) are used.

Fig. 1: Schmidt hammer strength tests.

Overview of arch bridge failures:

- Incompatible deformations (deformations that are subject to changes in the original geometry),
- Destruction of material caused by either chemical or physical processes,
- Material discontinuities (cracks), see Fig. 2,
- Material loss (falling stones),
- Damage to auxiliary elements (damaged seal),
- Deformation damage (deformation on the structure, which is not subject to change of the original geometry, eg sliding parapet walls),
- Contamination (natural cover, soiling).

Fig. 2: Opening and falling mortar from joints in a brick vault.

4. Analyse of Some Arch Bridges of the Railways of the Slovak Republic

4.1. Chmaroš Viaduct

The bridge building is located at km 82,589 and is part of the single-track non-electrified railway line no. 173 Red Rock - Margecany. It is part of the connection Zvolen - Banská Bystrica - Margecany - Košice and is a component of the so-called Central Slovak transversal. At the same time, the line connected the Zvolen junction through the Hnilec valley with the Košice - Bohumín railway. In the direction, the bridge is led in an arc with a radius of 300 m.

The Chmaroš Viaduct is a stone arched brick railway bridge with a concrete infill built in 1933. It bridges the valley, the forest road and the Chmaroška brook, after which it is named. The bridge has nine arches with a width of 10 meters, has a variable height, max. 18 m and the length of the bridge is 113.4 m. On the bridge, there are rails with a normal gauge of 1435 mm, type S 49, mounted on concrete sleepers mounted in a gravel bed 0.3 m above the sill made of stone blocks.

Fig. 3: Deformeter SDM 250/10 and a practical example of measuring the width of the monitored crack.

Faults formed by vertical cracks and fissures in the pillars of the building have been repeatedly measured on the bridge structure since August 2021 [4]. For their comprehensive analysis, measuring points were installed in the aggregate. At these points, the crack width was measured using an SDM 250/10 strain gauge (Fig. 3). The measurement accuracy is determined by a value of 1/100 mm, which is calibrated on the basis of data provided by the Railway Research and Development Institute [4].

The bridge has a long-term non-functional drainage, which causes water to flow into the mortar joints and aggregates through the supporting structure of the bridge, in which local cracks and calcium incrustations subsequently appear. The recorded cracks are located on the north side of the bridge, which is in the shade all year round. On the other hand, the south side is exposed to sunlight all year round and thus it dries out even in winter. Due to the falling temperature and water freezing in the bridge structure, the cracks widen in the winter. On the contrary, crack closure was recorded as temperatures increased.

Whether the cracks are demonstrably widening in the long run will be seen in a longer-term measurement, in which the crack width values are compared throughout the year. In the long run, underestimating the non-functional drainage will lead to further disruption of the stone cladding of the pillars, leakage of vaults and gradual loss of mortar in the joints, which may lead to a reduction of the active area for normal stresses and thus to reducing the load capacity of the bridge. The assessment of the condition of the viaduct, taking into account failures and degradation of materials, must prove a static calculation.

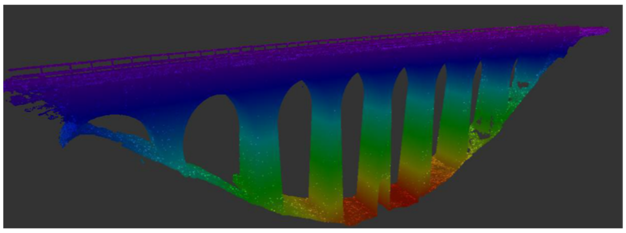

Fig. 4: The result of the scan is a processed 3D model of the Chmaroš Viaduct in the Leica Cyclone software, converted to the required dxf format.

In fig. 4 shows the output from 3D laser scanning. This method of geodetic observation is based on determining the spatial coordinates of detailed points by the spatial polar method.

4.2. Marchegg Viaduct

A 474 m long bridge (Fig. 5) was built across the Morava River between the Marchegg and Devínska Nová Ves stations, which was one of the largest in the monarchy at the time. The bridge consisted of ten inundation brick vaults with a diameter of 10x15 m on both sides and the middle part, which crossed the river and consisted of a wooden double-folded dam structure spanning 2 x 43 m.

Fig. 5: View of the Marchegg Viaduct from the Slovak side.

The construction of the bridge began only in November 1846. The construction of the bridge was ensured by the Italian business firm Felice Tallachini. However, it had to be interrupted by a series of obstacles - the extreme winter, the unusually high level of Moravia River, the outbreak of a typhus epidemic among the workers, which claimed many lives. It was completed after an effective construction time of eight months in the autumn of 1847, which, given the then state of construction machines can be described as excellent performance.

The wooden part of the bridge was destroyed during the Prussian-Austrian war in 1866 by the retreating Austrian army. After its temporary repair, the operation was resumed on August 27, 1866. The final restoration was not completed until 1868, while the wooden makeshift was replaced by a continuous steel truss girder structure, folded multiple times with an upper deck with a span of 2 x 43 m. The retreating fascists blew up the iron dam structure with the upper bridge deck from 1868 on April 6, 1945.

On the bridge object in the vaulted part, the defects are mainly formed by longitudinal cracks in the vaulted ceiling. As part of the diagnostics, crack targeting and mapping were performed.

Fig. 6: Position of the vehicle at the critical point of the vault.

At the same time, a static load test was performed. The position of the vehicle at the critical point of the vault is shown in Fig. 6.

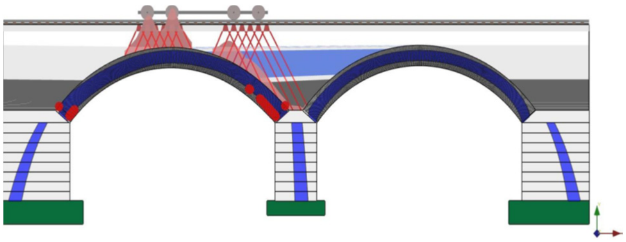

Fig. 7: Model of the arch part of the bridge in the LimitState Ring program.

The static assessment of the bridge was performed in the software LimitState RING (Fig. 7).

Given the results of diagnostics and static analysis of the bridge, it is necessary:

- operate a bridge with a maximum axle load of 20 tonnes (load category C3),
- operate the bridge at a maximum speed of 70 km / h,
- replace the expansion device (its vertical movement when passing the individual axles of the trains shows a dynamic excitation on the vault) [5].

5. Conclusion

The paper presents the current possibilities of using diagnostic methods, methods of measuring strength characteristics, crack widths, static load tests on arch bricks made of brick or stone. Within the long-term cooperation of our department and VVUŽ ŽSR, there is a tendency to continue in the given issue, as some bridges of this type have already attacked or exceeded the age of 100 years. Particular attention must also be paid to the preservation of the technical and cultural heritage of our ancestors.

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