Inspection and Assessment of Masonry Arch Bridges

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The importance of masonry arch bridges as a traffic network element calls for a thorough analysis focused on both structural stability and loading capacity of these historical structures, considering the usage of these bridges in contemporary traffic conditions. As longitudinal cracks do not necessarily present an inevitable collapse mechanism, analysis of the causes is crucial for evaluating the serviceability and functionality of the bridge investigated.

stone bridge arch barrel deformations longitudinal cracks

1. Introduction

Older stone bridges are part of the rich historical heritage. Only a few of them remain to date in Balkan countries. after many of them suffered damage in their past. Nowadays, they are witness to cultural and social features of the period they were built in. Most of these bridges were designed centuries ago, being built according to empirical rules not matching the loads of contemporary traffic. The excellent durability and carrying capacity of masonry arch bridges is shown through their continuous use, as they are still in service with the massive use of motor vehicles that replaced carts [1]. The Industrial Revolution led to the development of new materials, mainly steel, and thus reinforced concrete, consequently, led to gradually declining masonry structures. The appearance of cracks, which is common in masonry structures, as well as the aging of materials and structural deformations, result in a decrease in stiffness requiring an investigation into the structural behaviour to ensure long-term stability [2]. Consequently, these structures need to be inspected to minimise damage risk since there is a possibility of experiencing significant economic and social losses [3]. The primary maintenance method of these bridges is focused on the proper direction of water runoff as well as on control of growing vegetation that appears on bridge structures [4]. Among stone bridges in Serbia, there are only a few that have not been altered before since most of them needed repairs and restoration in the length of time. Any further intervention on these structures requires a careful and cautious approach to maintain structural stability and another usage without compromising its architectural and monumental value. Hypotheses can be made based on the previously observed and read as follows: To establish the proper treatment of a masonry arch bridge to prevent any further deformation and opening of the existing cracks, it is necessary to study their structural behaviour as well as to determine the causes of the damage. These can only be conducted based on the analysis of features of both the bridge itself and building materials used.

2. Inspection and Assessment of Masonry Arch Bridges

The bridge presented in this case study is listed as a part of the Spatial Cultural-Historical Units of Great Importance in the Republic of Serbia. Due to its position, this bridge still represents one of the primary connections in the city of Ivanjica, which leads to its use daily. The research presented in this paper, including geological, geophysical, structural and biological analysis of the bridge, indicates permeation of different deterioration processes, whose negligence may lead to the system's severe decay or even collapse.

A detailed approach to data collection and analysis of the bridge structure and the necessary steps for static restoration were previously discussed in the paper. Geological testing was crucial in the analysis process, as longitudinal cracks can also result from foundation disruption [5]. Extensive research in this area eliminated the assumption that movements of the foundation lead to crack development. However, due to the geological composition of the rock, its schistose and that it has the fault occurrence, regular maintenance of the bridge is necessary to prevent the loss of stone material, which can be caused by vegetation as well. On the other hand, geophysical testing gave important observations on the moisture content of materials used. This aspect of the research showed that changes in the electric conductivity of materials used were relevant indicators of the change in moisture content through the bridge's structure. This information was crucial for a full understanding of the processes occurring and predicting possible future behaviour. The change in moisture content indicated two main problems. Firstly, with this occurring, stiffness of the infill material decreases, forming higher pressure on wing walls, and thus leads to crack propagation. Secondly, the presence of moisture develops a suitable environment for ice formation, thus leading to the degradation of the material's inner structure. As the sandstone used is classified as medium-hard, appearance of inner stresses could cause significant damage. Nevertheless, biological testing also showed that the material's inner structure was not degraded by biological colonisation, although superficial changes in colour can be seen with the naked eye. Apart from the aesthetically altered surface caused by the presence of lower plants and the development of black crust, the influence of these degradation processes did not change structural behaviour of the construction so far.

As mentioned above, both physical and mechanical testing was developed, giving all the necessary data for structural analysis. Precise defining of the bridge's geometry was crucial for further study and numerical models of bridge construction. This research determined the bridge's asymmetrical foundation, which resulted in a more significant load from the fill of the bridge on the left side of its construction. This has also affected the asymmetrical distribution of loads, causing greater deflections on the left side of construction. Consequently, added traffic loads on this side of the bridge increases deflections in that area but also causes the uplifting of construction elements on the other side, where longitudinal cracks appear. Loads on the right side of the structure also induce deflections, resulting in great dilatations, up to 6 mm, which stones cannot uphold.

The leading cause of the longitudinal cracks are shear stresses that appear when the live load is applied. Significant shear stresses in the transverse direction are expected in the barrel, as the live load defined by standards for vehicle zones is much higher than for pedestrian ones. This leads to fractures in stone structure because of the low capacity of sandstone to shear stresses. The appearance of these cracks did not lead to the collapse of the bridge, as they show limited bearing capacity in the transverse direction, but to the formation of an alternative structural solution, two independent arches. On the other hand, following the ingress of moisture, the existence of a crack leaves an open path for the moisture entrance, thus continuing the process of degradation of the inner structure. It is well known that, even though moisture does not directly influence mechanical degradation, its impact on the degradation of the material's inner structure is significant. The city of Ivanjica, which belongs to the Moravica district, is famous for its large temperature oscillations, which is a condition that favours processes of physical degradation of material in the presence of moisture content. To investigate potential future behaviour of the bridge that could lead to the collapse, three possible mechanisms have to be evaluated: the opening of additional hinges in the arch barrel, which could lead to the formation of the mechanism; the out-of-plane behaviour of the spandrel wall; and the possible rotation of different parts. This is because the longitudinal crack forms two ''L'' cross sections, whose rotation might lead to the collapse of the system. All three possible failure mechanisms should be investigated more thoroughly to define the limit conditions of the subject of this case study, thus defining its serviceability. Although a significant reserve of strength exists even after the crack formation, the weathering cycles and vegetation growth, recognised and investigated in this research, will modify the structure's stiffness. In this context, it is essential to provide remedial measures directed towards cleaning biological colonisation and repointing the crack to prevent moisture ingress, allow movement and independent behaviour of separated parts.

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