Renovation and repair of a masonry arch bridge in Thumaide, Belgium

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Summary

A new windmill park is to be built in the centre of the Hainaut province in Belgium. During construction heavy transport will need to pass over a 20m span masonry arch bridge built at the beginning of the twentieth century. Currently, the spandrel walls have deformed significantly due to the pressure of the backfill. The spandrel walls and the arch show cracks and locally bricks are missing. The bridge, that crosses the RaVel (a network for cycling in the Walloon region), therefore needed a well-considered renovation to guarantee the safety of cyclists passing under the bridge. Also verification was required for the exceptional transport during construction of the wind mill park. This paper will discuss in detail how the different analysis models and strategies complemented each other, and helped convince the client to restore rather than demolish this masonry arch bridge.

Keywords: Masonry arch bridge; renovation; repair; line of thrust; theory of plastic hinges.

1. Introduction

Renovation studies generally require two types of analysis. First, an analysis of current problems and eventual damage should be made. Finding out what the reasons of current problems are is crucial in avoiding future damage by improving the structure. Secondly, the design parameters that were initially considered are generally unknown and future use can thus not be verified by comparing future situation or loading with the initially-considered parameters.

Figure 1: State of the bridge before renovation

The study of this bridge can be summarized into two basic questions. Is the bridge capable of carrying the exceptional transport during construction of the windmill park? Can damage be repaired and, more importantly, be avoided in the future, taking into account that the bridge will be used by exceptional transport? Both questions demand a different strategy or design approach and will be discussed in further detail in this paper.

https://doi.org/10.2749/222137813806483002

2. Ultimate Limit State

2.1 Type of analysis

Commonly used Finite Element Methods with elastic material behaviour were not found appropriate for the verification of the ultimate limit state. A FEM analysis would result in inordinately high tensile stresses in the masonry structure. In reality, cracks will be formed where tensile stresses occur and forces will be redistributed. Therefore, FEM analysis considering elastic material behaviour is too conservative. FEM analysis considering non-linear material behaviour can be used for the ultimate limit state verification. The disadvantage of this method is that it is very time consuming. In designing, it is sometimes interesting to invert the designing problem: instead of finding out if a given load can be carried by the structure, it might be interesting to find out how much load can be carried by the structure. It is difficult to obtain such results by FEM analysis. A more appropriate type of analysis is based on the theory of plastic hinges, in combination with an advanced line of thrust analysis.

2.2 Design Parameters

An important parameter in calculations of masonry structures is the geometry. Examples are known in which calculations based on an approach of the real geometry resulted in sufficient resistance, while in reality the structure collapsed. Therefore, a very accurate measuring was demanded. Because of the poor state of the 20m span masonry arch bridge, a reduction of the total thickness of the arch was taken into account, leaving a total design thickness of 90cm considered in calculations.

The masonry is brick with a lime sand mortar, which is a relatively flexible mortar. The design value of the compressive resistance of the masonry was based on sample tests: 1,8MPa (including safety factors).

Horizontal ground pressure of the backfill has a stabilizing effect on the stability of the masonry arch.

2.3 Results of Analysis

The most critical load configuration is asymmetric loading of the bridge with design loads according to load model 1 of EN 1991-2. The vehicle loads specified by the client are higher than these loads, but the load concentration is lower (i.e. the loading is better spread).

To find the loading that corresponds with structural failure, the variable loading needs to be increased iteratively until a situation is reached where only one line can be drawn within the arch with a maximum of four plastic hinges. In this situation, structural collapse will occur. If loading is lower than this value, the structure is stable. Calculation with the critical load configuration showed that structural collapse would occur if the bridge is loaded with 40 per cent more loading than the ULS combination value of the traffic load (i.e. almost 90 per cent more than the characteristic value).

The masonry arch has sufficient capacity to resist the specified loadings. It was thus not necessary to demolish the ancient bridge and build a new bridge.

3. Repair Analysis

FEM was not found appropriate for ultimate limit state verification. However, FEM proved to be useful to analyse stresses for serviceability state verification. Stress analysis shows that the spandrel walls, which are connected to the arch, work as high beams, causing tension stresses in the bottom. This tensile stress pattern found in Scia Engineer corresponds with the crack pattern in the bridge. The spandrel walls working as relatively stiff beams in combination with horizontal settlement of the foundations explain why bricks are falling off.

A solution was conceived such that the masonry works solely in compression as an arch, rather than as a beam by introducing vertical joints in the spandrel walls.