Investigation on the restoration of the iron suspension bridge at the castle of Wissekerke

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Abstract

The two world wars have seriously limited the number of historical bridges in Belgium. Many strategic bridges have been blown up or bombed. Therefore, the history of bridge building can only be examined by (small) ornamental bridges, for example in castle parks and gardens.

The oldest surviving wrought iron suspension bridge in Belgium and one of the oldest on the European Continent is spanned over the pond at the castle of Wissekerke in the district of Bazel-Kruibeke. The Brussels engineer Jean-Baptiste Vifquain designed it in 1824. In spite of the modest span of 23 meters, the bridge is of great industrial archaeological value, because of its historical and structural uniqueness.

Since 1981, the bridge at Bazel is a protected historic monument. Because of the lack of maintenance and the specific construction type, different parts of the ironwork are broken or bent, and strongly corroded. So, at present, this historical heritage is in very poor condition and some urgent maintenance and restoration work should be conducted. Fortunately, the council of Bazel intends to buy the park and the bridge. As from August 2004, they invited us to start with the restoration of this historical suspension bridge.

Keywords: restoration, suspension bridge, cast iron, wrought iron, 19th century, Belgium

1 Introduction

Although (small) historic footbridges are more numerous, because most of the (large) historical traffic bearing bridges were bombed during the world wars, pedestrian bridges are often less known and therefore their construction and maintenance receive less attention. This paper discusses the approach of the restoration of the iron pedestrian suspension bridge, spanned over the pond at the park of the castle Wissekerke, located in the district of Bazel-Kruibeke in Belgium.
First we will demonstrate the important industrial archaeological value of this monument. Therefore we will elaborate the historical and structural developments of bridge building. Once this has been outlined, we will explain our approach of the restoration research. We will emphasize mechanical properties, calculations and results of the examined historical cast and wrought iron. To conclude this paper, we will illustrate and discuss some of the possible restoration ideas and their implications.

2 A Belgian monument with both historical and industrial archaeological value

The first bridges in history are found nearby rivers. Early traderoutes followed the contours of the countryside and the most favourable geological routes. Bridges only were used if unavoidable, for instance at river crossings without fords.

The industrial revolution and the discovery of iron as a building material changed this attitude. Iron was thought to be the new material that would solve all limitations and (fire)problems of wood constructions. It did not, but the introduction of cast and wrought iron made new forms, structures and challenges possible. As from that era on, bridges were also used for prestige. Especially suspension bridges were held in high regard: these structures made it possible to build long spans at locations where it was desired to have an architectural landmark.

2.1 International evolution of the 19th century iron suspension bridges

Although it is not a suspension bridge, we have to mention that the oldest surviving iron bridge was built in 1779. Thomas Pritchard designed the Ironbridge over the River Severn in Coalbrookdale. Abraham Darby III and John Wilkinson used cast iron to build it. The bridge has a span of 30 meters and is still in use. The shape is logically based on the old Roman masonry arch bridges, considering the fact that cast iron resists compression very well, but reacts poorly to traction. On the other hand, the construction details are typical connections used for wood constructions. The first cast iron bridge on the Continent however, was not built until 1802 in Paris: the Pont des Arts, but it was torn down in 1885 and replaced by a similar one [2].

Suspension bridges are no invention of the industrial revolution. Cables and chains were used already in the first century after Christ for footbridges in China, India and South-America [3]. The principle of wrought iron chains was discovered in the sixth century A.C. [4]. None of those bridges were stiffened and the deck was attached directly to the chains. As a consequence, they were not very stable when walked over.

![Figure 1: (left) main chain from the bridge of Wissekerke (1824) with linked eye-rods; (right) main wire cable from the suspension bridge of Antwerp (1868-1869)](image)

Although the first catenary suspension bridge with a separate pending bridge deck was already drawn in 1595 by Faustus Verantius, the first footbridge with wrought iron chains was not built before 1741, viz. across the River Wear in Durham, England. Sixty years later, in 1801, James Finley designed and built the first suspension bridge capable of bearing traffic loads in the United States of America. He had a sound grasp of the way these structures work, and in 1808 he patented his building system. He used the catenary to determine the
form and dimensions of the elements. Between 1808 and 1824 he built 11 bridges in accordance with his patent. As a consequence, he has often (falsely) been referred to as the inventor of the iron suspension bridges.

When discussing the evolution of classical suspension bridges, it is important to take a closer look at the main chains. They can consist of chain elements (so-called ‘eye-rods’) or wire cables (see figure 1). Because the industrial revolution started in England, the earliest chain suspension bridges were built there. In contrast with James Finley’s flat chain links, English engineers applied flat or round bars with an eye at the beginning and the end. The main chain consisted of small wrought iron ‘eye-rods’ with bolted joints or hinged together by means of these eyes. Some fine examples can be found, such as Sir Samuel Brown’s Union Chain Bridge (1820) and Thomas Telford’s Menai Straits Bridge (1826). German engineers also applied chain links. The oldest German iron suspension bridge dates from 1827 in Malapane.

In contrast to England and Germany, French, Swiss and American engineers preferred to use cables. Under the influence of the French engineers Claude Navier, Henri Dufour and Marc Seguin, people realized that cables were a substantial improvement compared to hinged chain elements. In 1823, Navier introduced the present analytical description of the catenary. He had a great theoretical knowledge concerning suspension bridges, but his practical competence was rather limited. Dufour, however, was the ‘intelligent producer’. His calculations were less complicated, but his bridges never constituted a harmonious whole. When building his first suspension bridge in 1823-1824, in St.-Vallier across the river Galloire, Seguin tried for the first time in history to increase stiffness by introducing a parapet, carried out as a truss. This had to prevent the oscillations caused by wind and the pedestrian induced vibrations when walked over it. Subsequent calculations demonstrate that his intuitive solution to stiffen the bridge was much better than Navier’s theoretical solution, who said it was sufficient to increase the dead weight of the deck and the resulting tension in the main cables [3].

2.2 The iron suspension bridge of Wissekerke

This bridge has a great historical and industrial archaeological value. The first blast furnace in Belgium that used cokes, was not built until John Cockerill introduced it in 1824. Iron was very expensive at that time and therefore, only used rarely. Nevertheless, Vifquain built his bridge that same year.

As Vifquain spent much time analysing English engineers, it was unavoidable that the bridge at Wissekerke was built in accordance with the typical English building features. Similar to the Union Bridge, Vifquain used eye-rods – a characteristic English mark – for the main chain of his bridge. Besides, this way the bridge fits well into the English landscape garden.

In spite of these characteristics, the bridge actually bears most resemblance to the 30 meter long pedestrian bridge from the Frenchman Marc Seguin over the French river Galloire in St.-Vallier, which was also built in 1823-1824 and was also stiffened by a guardrail carried out as a truss. In contrast to this French bridge however, Vifquain’s bridge has a very light appearance.

![Figure 2: (left) the castle of Wissekerke; (right) the iron suspension bridge across the pond of the castle park](image)
3 Material characteristics

Historic iron exists in various forms, each manufactured in its own way and having its own properties. Moreover, the earlier suspension bridges are rather fragile in comparison with for instance masonry arch bridges. They have no reserve of hidden strength. So, when dealing with the restoration of historical iron bridges – and historic iron structures in general – it is evident to have concerns about the risk of failure. Some of the large historic bridges have two or three parallel chains on each side, usually positioned vertically above each other, to reduce the risk of collapse. Most early bridges, especially smaller pedestrian bridges like the one at the castle of Wissekerke, do not have this kind of security measure. Therefore it is very important to determine the material characteristics as exactly as possible.

Information regarding the construction date (1824) and a visual inspection of the bridge made it possible to determine that the entire bridge is built using wrought iron, with the exception of the pillars at the beginning and the end of the bridge and their support pillars, which are made of cast iron.

Some of the members of the bridge are broken, so we could get hold of some samples. The metallographic research proved us right on the wrought iron and it provided the additional information that we had to deal with nodular grey cast iron for the pillars and their support pillars. This kind of cast iron is one of the strongest sorts. Still, for security reasons, we decided to use the conservative strength values of the London Act of 1909 (see table 1). A quick first calculation – according to the line of thought of the Eurocodes – demonstrated that we could keep the values of the cast iron elements. This was a very conservative estimation, and still they had enough strength reserve. Yet, we could not maintain these values for the wrought iron. Due to these results and the fact that there are important fluctuations in the production and the quality of wrought iron in the beginning of the 19th century, we were compelled to perform our own tests.

The metallographic research already showed the wrought iron was well hammered. There was just a limited number of impurities and they were well orientated, in the longitudinal direction (see figure 4). To determine a more accurate value, we first carried out some non-destructive Vickershardness measurements on the samples. After all, there is an empirical relation between these results and the ultimate tensile stress (UTS), and between this UTS and the yield stress. Fortunately, the samples were big enough to perform some tensile tests too (see figure 5). The results of these tensile tests are shown in table 2. We can conclude that the quality is very good. The yield stress is high and there is a rather large plastic deformation range (± 90 N/mm²). These results may seem very high, but they are confirmed by the hardness measurement. The values of this hardness measurement are only about 4-5 % higher than those from the tensile tests. Moreover, the elongation at fracture is more than 10 %. Thus, in spite of the limited tensile strength testing, we can place reasonable confidence on these results [6]. Furthermore, the proportion between the yield stress and UTS is about 73 % according to the tensile tests. This corresponds well to the proportion 3 to 4 of some tests that have been carried out in 1814 [7]. Of course, in our calculations, these values will have to be adjusted with some safety coefficients. In accordance with the Eurocodes, the design yield stress for the wrought iron of the bridge from the castle Wissekerke is 200 N/mm² and the design UTS 290 N/mm².

Table 1:  Ultimate compression and tensile strength and elasticity modulus of wrought and cast iron according to the London Act 1909 [5]

<table>
<thead>
<tr>
<th></th>
<th>Wrought iron</th>
<th>Cast iron</th>
</tr>
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<tbody>
<tr>
<td>UTS</td>
<td>290 N/mm²</td>
<td>320 N/mm²</td>
</tr>
<tr>
<td>Yield stress</td>
<td>200 N/mm²</td>
<td>220 N/mm²</td>
</tr>
<tr>
<td>Elongation at fracture</td>
<td>± 90 %</td>
<td>± 10 %</td>
</tr>
<tr>
<td>Proportion</td>
<td>3 to 4</td>
<td>3 to 4</td>
</tr>
</tbody>
</table>
Compression [N/mm²] 77 124
Tensile [N/mm²] 77 23
Elasticity [kN/mm²] 200 84-94

Figure 4: (left) metallography in longitudinal direction of the sample of the bridge of Wissekerke (wrought iron, etched with nital, 50x magnified); (right) metallography in transverse direction of the sample of the bridge of Wissekerke (wrought iron, etched with nital, 100x magnified).

Figure 5: (left) original samples of the bridge of Wissekerke; (right) dimensions of the samples for the strength testing

Table 2: Results from the tensile tests to determine the UTS and yield stress [N/mm²] and the elongation [%] of the wrought iron rods from the bridge of Wissekerke

<table>
<thead>
<tr>
<th>Rod</th>
<th>Rod 1</th>
<th>Rod 2</th>
<th>Rod 3</th>
<th>$\epsilon_b$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma_y$</td>
<td>259</td>
<td>245</td>
<td>268</td>
<td>257</td>
</tr>
<tr>
<td>$\sigma_{UTS}$</td>
<td>343</td>
<td>357</td>
<td>350</td>
<td>350</td>
</tr>
<tr>
<td>$\epsilon_b$</td>
<td>(20)</td>
<td>15.4</td>
<td>16.2</td>
<td>17.2</td>
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</table>

4 Calculations

So far we have not been able to retrieve any of the original calculation notes from the engineer J.-B. Vifquain. So we neither know for how many people this bridge was designed, nor what stress limit he used. We do know,
However, that the bridge was a private pedestrian bridge, which makes it likely that its capacity is rather limited. Historical research showed that bridges often were not calculated at all, or, if they were, only the main chain or cable was, as if it was one continuous cable from one pillar to the other. Besides, except for Navier’s equation, the applied calculation methods were not correct at all. Connectors were not considered, except for some cases where some tensile tests on life-size models have been done.

We chose to re-calculate this bridge according to the line of thought of the Eurocodes. The calculations show that the main chain is able to bear 0.82 kN/m² or about 41 people. The hangers can carry this amount without a problem. As we have to deal with a chain, it is necessary to check on the connectors too. This verification showed that the bolts are the weakest link. Because only one bolt at the top of each pillar has to carry the entire weight, they fail due to shear at a load of 0.41 kN/m² or the equivalent of only 20 people.

Apparently this is typical for these types of bridges. In 1831, sixty soldiers marched over the Broughton Bridge (1828). Due to the resulting resonant vibrations the bridge collapsed. A thorough examination concluded that the principal fracture took place in a bolt in the main chain [8].

5 Restoration options

In December 1967 the Silver Bridge across the Ohio River between Point Pleasant and Gallipolis in the USA collapsed without warning after 40 years of service [6]. 46 people were killed, 9 injured. An eyebar fractured due to stress corrosion or corrosion fatigue. This problem occurs often, particularly at the mid-span where the hangers are the shortest (see figure 6). This example shows that, even though a construction is in use since many years without a problem, it still can collapse without a warning, leading to a real disaster. Luckily, in recent years, early suspension bridges are more and more considered as heritage structures, requiring special care and attention.

Figure 6: (left) broken hanger at the mid-span; (middle) part of the truss that is bent, broken and corroded; (right) wooden deck in bad condition

Since 1981, the bridge of Wissekerke is listed as a historic monument. In theory, this means it has to be inspected and maintained on a regular base. Reality however, shows that this bridge stands for over 180 years and that it is seriously defective at the moment (see figure 6). The main problem in this case is that the local council and the owner, viscount Jean Villain XIII, are in dispute about who has to pay for the maintenance. The viscount has no money, and moreover, he lets the park and bridge to the local gouvernement. The local council on the other hand refuses to pay, because they do not own the park and bridge. Fortunately, the local council intends to buy the park and bridge, and we have already been contacted to assist at the restoration.

In spite of the fact that, at this point, our research is far from completed, we still can draw some conclusions towards the possible restoration works. We hereby focus mainly on the ironwork. Nevertheless, other elements like the land abutments and the wooden deck must be thoroughly examined as well.

First of all, it is important to decide whether or not the bridge has to become a public bridge. If not, the bridge can be kept as it is, and just some (minimum) preservation works have to be carried out. Since the only degradation of the cast iron elements is purely ornamental, casting the missing or broken elements should not be much of a problem. The situation for the wrought iron elements is different. Most of the structural elements can be preserved, if necessary after they have been thermomechanically straightened. This method has been successfully applied to the Metal Bridge in Caledon Ireland, built in 1844 [8]. However, a few structural elements have to be replaced completely. Regarding this, it is important to mention not to use stainless steel, since this could cause intermetallic corrosion in contact with ordinary steel or iron. It is better to use iron with a low carbon percentage, similar to the historic wrought iron. Non-structural iron elements do not have to be replaced. New
pieces could be welded onto the original material. Of course, to finish the preservation, it is of the utmost importance to apply a good corrosion protection and to formulate and set up a proper maintenance scheme. However, the mayor of Bazel-Kruibeke would like to open the bridge to the general public. Therefore, the bridge certainly has to be strengthened. After all, the capacity of the bridge – even in fully intact condition – is very limited, since it originally was a private bridge. This would have important consequences. Yet, if the bridge would not be opened to the general public, it is very likely to be in bad repair.

Once one of these two alternatives is chosen, we must decide whether the bridge will be left as it is – to maintain as much of the original material as possible – or not. If the second option is chosen, some external bearing structures will have to be placed. It would be possible to put additional supporting beams, a second supporting cable on each side, a shore at the mid-span, a second guardrail on both sides to narrow the deck, … Then again, it is important to mention that these options have crucial visual implications and that this way the bridge loses her suspended character.

On the other hand, it is also possible to leave the bridge visually unchanged, and strengthen it by adding some reinforcements and new materials. At this time, old (smaller foot)bridges are often quietly dismantled and (partially) replaced. In many cases the chains are replaced with composite cables to provide extra strength and security, but this way of restoration leads to a great loss of historic material. For the moment, we still tend to use solutions that do not disturb the original configuration, and keep most of the original material, except if it is unavoidable. A first reinforcement could be made by replacing all bolts by new 8.8-bolts, since calculations have shown that these are the weakest points of the bridge. This solution removes only a very limited amount of the original material. With this intervention the bridge could bear 0.82 kN/m² or 41 people. This is two times more than in the original configuration, but still insufficient for a public bridge. After this intervention, the main chain is the restrictive component.

6 Conclusions

As we outlined in the first part of this paper, the bridge at the castle of Wissekerke has a great historical importance. It is the oldest iron suspension bridge of Belgium and one of the oldest on the European Continent. Unfortunately, at present it is in very bad condition and some urgent restoration works have to be carried out to prevent the loss of this industrial archaeological monument.

Material tests have revealed that the iron, used by J.-B. Vifquain, was of a very high standard. Nevertheless, calculations have shown that the bearing capacity of the bridge is inadequate, if the bridge is upgraded to a public footbridge.

Unfortunately, in managing older suspension bridges it is not possible to follow ideal principles on all occasions, as there are invariably constraints to be taken into account. So, finding a solution, accepted by both the local council of Bazel-Kruibeke and the Belgian Council on Monuments and Sites, to increase the bridge’s strength is not obvious, certainly not if the bridge is upgraded from a private to a public bridge.

Until now, we have not found any satisfactory solutions. Therefore, we are presently investigating some other restored Belgian historical suspension bridges, in order to compare the restoration options. Furthermore, we plan to make more complex re-calculations, using software, to gain more insight in the functioning of and the interaction between the different parts of the bridge. We are confident that the results of these inquiries will help us to formulate an appropriate solution for this particular Belgian monument.

References