THE IRON SUSPENSION FOOTBRIDGE OF WISSEKERKE: MATERIAL CHARACTERISTICS

Michael de Bouw  
M.Sc. in Engineering: Architecture  
Vrije Universiteit Brussel – Architecture  
Brussels, BELGIUM

Ine Wouters  
Prof.Dr.M.Sc. in Engineering: Architecture  
Vrije Universiteit Brussel – Architecture  
Brussels, BELGIUM

Summary

The oldest surviving iron suspension bridge in Belgium and one of the oldest on the European Continent is spanned over a pond in the park of the castle of Wissekerke in the district of Bazel-Kruibeke. The Brussels engineer Jean-Baptiste Vifquain made its design in 1824. In spite of the modest span of 23 meters, the bridge is of great value, both for history and industrial archaeology because of its historical and structural uniqueness.

Since 1981 the bridge at Bazel is a protected historic monument. At present, this historical heritage is in very poor condition and some urgent maintenance and restoration works should be conducted.

The paper focuses on the determination of the material characteristics, as this is a very important step in the restoration process.

Keywords: restoration; suspension footbridge; early 19th century (1824); Jean-Baptiste Vifquain; wrought iron; cast iron; material characteristics.

1. Introduction

Although (small) historic footbridges are more numerous, because most of the (large) historical traffic bearing bridges were bombed during the two world wars, pedestrian bridges are often less known. Therefore, their construction and maintenance receive less attention. This paper discusses the approach of the determination of the material characteristics and the recalculation of the iron pedestrian suspension bridge.

First we will focus on the industrial archaeological value of this monument. Once this has been outlined, we will explain our approach of the restoration research. We will emphasize on the 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. An important Belgian monument

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 19th-century iron suspension bridges

Suspension bridges are no invention of the industrial revolution. Already in the first century after Christ, cables and chains were used for footbridges in China, India and South-America [2]. The principle of wrought iron chains was discovered in the sixth century A.C. [3]. 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.

![Fig. 1: hinged eye-rod connection between the main chain and hanger from the suspension bridge of Wissekerke (1824)](image1)

![Fig. 2: connection between the main wire cable and hanger from the suspension bridge of Antwerp (1868-1869)](image2)

When discussing the evolution of 19th-century iron 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 (Fig. 1 & Fig. 2). Because the industrial revolution started in England, the earliest suspension bridges were built there. In contrast with the flat chain links of the American James Finley, 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. 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 [4].

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.

A more detailed description of this evolution can be read in “Investigation on the restoration of the iron suspension bridge at the castle of Wissekerke” [5]

2.2 The bridge of Wissekerke

In spite of the modest span of 23 m, the wrought iron suspension footbridge at the castle of Wissekerke 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 [6]. Iron was very expensive at that time and therefore, only used rarely. Nevertheless, commissioned by the lord of the castle Philippe Vilain XIII, the Brussels engineer Jean-Baptiste Vifquain built his bridge that same year. This causes the bridge to be built in the same period as the first suspension bridges of Sir Samuel Brown and Thomas Telford (see § 2.1).

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

At this moment, as the bridge is in very bad condition, the restoration process has started. As the castle park has become a public park, the discussion is going on whether or not the bridge should become public too. Therefore, the bearing capacity of the bridge has to be determined by investigating the material characteristics and by adequate recalculations.
3. Determination of the material characteristics

Before we can recalculate the load-bearing capacity of this bridge, we must determine the nature and quality of the applied iron. Historic iron exists in various forms, each manufactured in its own way and having its own properties. As the earlier suspension bridges are rather fragile in comparison with, for instance, masonry arch bridges, they have no reserve of hidden strength. Therefore, 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 clarified that the entire bridge consists of 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. As the properties of these materials, found in literature, are widely divergent, it is necessary to perform a metallographic research, some hardness measurements and tensile tests to gain a clear insight into the constitution and the quality of the iron. Fortunately, some of the members of the bridge are broken, so we could get hold of three samples to perform these tests (Fig. 5).
3.1 Metallographic results

The metallographic research consists of two examinations. First, the three samples are put under an optical light microscope. Hereafter, we make use of a Scanning Electron Microscope (SEM) linked to an Energy Dispersive X-ray (EDX) micro analyzer to make greater and better magnifications and to perform a semi-quantitative element analysis.

3.1.1 Cast iron sample [sample (3) in Fig. 5]

The visual inspection as well as the SEM and EDX analysis prove that we have to deal with grey cast iron with graphite flakes: the black lines in Fig. 6 show the graphite (almost pure carbon) and Fig. 7 shows the presence of iron (Fe), carbon (C) and silicon (Si), as expected for cast iron.

It is interesting to see that almost the whole matrix consists of pure pearlite (area 2 in Fig. 6 and the presence of silicon in Fig. 7). Pearlite makes the material harder. Therefore, it reacts well to compression forces. Fig. 7 reveals also the presence of phosphorus (P). This characterizes the small areas of steadite (area 1 in Fig. 6) in between the pearlite. Together with the high presence of graphite (C), this phase increases the resistance to corrosion. Indeed, after standing for over 180 years, our visual inspection revealed almost no corrosion of the cast iron pillars.

3.1.2 Wrought iron samples [sample (1) & (2) in Fig. 5]

To determine the quality of the wrought iron, it is necessary to examine both the longitudinal as well as the transverse section of the samples. Fig. 8 and Fig. 9 show that the matrix consists of pure ferrite. The black lines and dots in these samples are contaminations. These inclusions consist mainly of manganese (Mn), silicon (Si) and phosphorus (P). On the magnifications it is clear that there is just a limited number of impurities. Moreover, we can say the wrought iron elements are well-hammered as the inclusions are all orientated according to the longitudinal direction of the elements. Therefore, we can conclude that they have little influence on the strength.

In contrast with the cast iron, wrought iron has (almost) no graphite. Therefore, it has little resistance to corrosion. Our visual inspection did, indeed, reveal important corrosion problems on the wrought iron elements.
3.2 Hardness measurements

As we have determined the constitution of the cast and wrought iron, we now will perform some Vickers hardness 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 ($\sigma_y$).

We carry out these tests on the wrought iron samples only, since a quick first calculation – according to the line of thought of the Eurocodes – demonstrated that we could keep the conservative strength values of the London Act of 1909 for the cast iron elements as they still have enough strength reserve (Ultimate Compression Strength UCS = 124 N/mm²; UTS = 23 N/mm²; E-modulus = 84-94 kN/mm²). Yet, we can not maintain these values for the wrought iron (UCS = 77 N/mm²; UTS = 77 N/mm²; E-modulus = 200 kN/mm²) [7].

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.

We carried out four measurements on the section of the sample of the parapet (23 mm x 22 mm) (area 1 in Fig. 5) and three on the one of the hanger (13.5 mm x 14.5 mm) (area 2 in Fig. 5). As we could not get hold of a sample of the main chain, we performed the tests on a sample of the parapet. This is a safe approach, since the main chain (31 mm x 14 mm) is thinner than the parapet and therefore, better hammered and harder. The resulting mean Vickers hardness for the parapet is 109 HV 20 and for the hanger 130 HV 20.

We know that there is an empirical relation of three to one between the Vickers hardness and the tensile strength in kg/mm². The relation between the yield stress ($\sigma_y$) and UTS is three to four [8]. This results in a mean UTS of 364 N/mm² and a $\sigma_y$ of 273 N/mm² for the parapet, and a UTS of 434 N/mm² and a $\sigma_y$ of 326 N/mm² for the hanger.

3.3 Tensile tests

The values of the hardness measurements provide a first estimation of the strength of the wrought iron elements. Nevertheless, tensile tests remain necessary to get accurate strength values that can be used for the recalculation. The sample of the hanger is too small for these tests. But, the hardness tests show that the hanger is stronger than the parapet. As a consequence, performing the tensile tests only on the sample of the parapet is (again) a safe approach.

To get an idea of the homogeneity of the wrought iron, we saw the sample lengthwise into three pieces and performed a tensile test on each piece. The results are given in Table 1.

Fig. 10: samples of the parapet sawn into three pieces for the tensile test. Fig. 11: dimensions of the samples of the parapet for the tensile test.
Table 1: Results from the tensile tests to determine the UTS ($\sigma_{UTS}$) and yield stress ($\sigma_y$) and the elongation at the breaking point of the wrought iron rods from the bridge of Wissekerke

<table>
<thead>
<tr>
<th>Rod 1</th>
<th>Rod 2</th>
<th>Rod 3</th>
<th>f_{mean}</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma_y$ [N/mm²]</td>
<td>259</td>
<td>245</td>
<td>268</td>
</tr>
<tr>
<td>$\sigma_{UTS}$ [N/mm²]</td>
<td>343</td>
<td>357</td>
<td>350</td>
</tr>
<tr>
<td>$\varepsilon_b$ [%]</td>
<td>(20)</td>
<td>15.4</td>
<td>16.2</td>
</tr>
</tbody>
</table>

The tested wrought iron has interesting mechanical properties. It has a high plastic deformation capacity and, both, the
UTS and yield stress, come close to those of a modern steel. These values are surprisingly high for wrought iron at the beginning of the 19\textsuperscript{th} century.

### 3.4 Conclusions of the material tests

The metallographic research proved us right on the wrought and cast iron. It provided the additional information that we have to deal with grey cast iron with graphite flakes for the pillars and their support pillars. This kind of cast iron is one of the strongest sorts.

Also, it showed the wrought iron is well-hammered. There is just a limited number of impurities and they are well-orientated, in the longitudinal direction. We can conclude that the quality is very good. The yield stress is high and there is a rather large plastic deformation range ($\pm 90$ N/mm$^2$). 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 [9]. Furthermore, the proportion between the yield stress and UTS is about 73 \% according to the tensile tests. This corresponds well to the proportion of three to four of some tests that have been carried out in 1814 [8].

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/mm$^2$ and the design UTS 290 N/mm$^2$.

### 4. Recalculation

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 recalculate this bridge according to the line of thought of the Eurocodes. In these calculations we did not take into account the possible positive effect of the parapet that is carried out as a truss. Considering the period and the measures of the parapet, it is clear that it was not designed to carry (a part of) the load.

The calculations show that the main chain is able to bear a weight of 0.82 kN/m$^2$ on the bridge deck or about 41 people in total. 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/m$^2$ on the deck 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 [9].

### 5. Restoration options

In spite of the fact that, at this point, our research is far from completed, we still can draw some conclusions towards some general restoration possibilities. We hereby focus mainly on the ironwork that stands for over 180 years and is seriously defective at the moment. 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 to avoid the collapse of the monument. However, if the bridge is to be opened to the general public, 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.
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 must be placed. Then again, it is important to mention that these options have crucial visual implications. 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 in total. This is two times more than the original configuration, but still insufficient for a public bridge. After this intervention, the main chain becomes the restrictive component.

6. Concluding remarks

In the first part of this paper we outlined the great historical importance of the bridge at the castle of Wissekerke. 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.

The metallographic research, the Vickers hardness measurements and the tensile tests that we have carried out, have revealed that the iron, used by J.-B. Vifquain, was of a very high standard. The grey cast iron used for the pillars, acting (almost) only in compression, is one of the strongest sorts. The wrought iron has little impurities and was well-hammered. The resulting strength of the wrought iron is comparable to that of a modern steel. Nevertheless, calculations have shown that the bearing capacity of the bridge is inadequate.

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 to increase the bridge’s strength is not obvious, certainly not if the bridge is upgraded from a private to a public bridge.

Presently, we are making more complex recalculation and models to gain more insight in the functioning of and the interaction between the different parts of the bridge. Furthermore, we will investigate four other restored Belgian historical suspension footbridges, in order to compare the restoration options and decisions. We are confident that the results of these inquiries will help us to formulate an appropriate solution for this particular monument.

7. References