Nineteenth-Century Iron Suspension Footbridges in Flanders (Belgium)

Ine Wouters, Michael de Bouw and George G. Nieuwmeijer

In Belgium no historic iron suspension road bridges are left due to the bombing during the two World Wars, lack of maintenance, and tightened building and traffic regulations. The history of bridge building can only be illustrated on the basis of small ornamental footbridges constructed in parks and castles.

Recently these iron suspension footbridges were listed by the VVIA (Flemish Association for Industrial Archaeology). This inventory holds five bridges dating from 1824 to 1905 with span lengths varying between 8 and 28 m. Although the number of bridges is rather small, their diversity of structural design reflects well the history of construction techniques: the replacement of catenary chains by cables and cast iron by wrought iron and later by steel, the increase of variety in profiles, the introduction of rolled "I" profiles, the stiffening of the deck by remodelling railings, and the improvement of the connections.

In contrast to road bridges, these park and castle bridges were luxurious additions –follies – as they served to overcome self-created obstacles like ponds. In all cases they were built at the same time as the park. The bridge served as an architectural and spatial landmark. It was part of a promenade, giving a grandstand view on land and buildings. These days, castles are being sold to local councils who turn the land into public and semi-public areas. As a consequence, the original private footbridges change into public ones. Although mainly pedestrians cross the bridge, one can speak of a change of use. This has as a result that the bearing capacity of the bridge needs to be upgraded.

What to do with these bridges now? Present-day pedestrian bridges are designed for a live load of 5 kN/m². None of the historical bridges can stand this load. The challenge of the (strengthening) intervention is to balance improvement and conservation without harming the originality of the bridge.

By describing the construction, the maintenance and the renovation of the five considered iron suspension bridges dating from 1824 – 1905, we come closer to an answer on the question mentioned above.

CASTLE BRIDGE IN WISSEKERKE 1824

The wrought iron suspension bridge at the castle of Wissekerke is one of the oldest remaining iron suspension footbridges in Europe (de Bouw 2005). Viscount Philippe Vilain XIIII (1778-1856) commissioned alterations to the castle, turning the park into an English garden and building a private footbridge over the pond. The Brussels engineer Jean-Baptiste Vifquain (1789-1854) was asked to design the bridge. Vifquain finished his studies at the Ecole Polytechnique in Paris in 1814. Thereafter, he travelled often to England to investigate the design of canals.

In the beginning of the nineteenth century important suspension bridges were built in America and England. At that time, each realization involved a valuable contribution to calculation methods, the way of stiffening the deck and the best form of the cable.

The bridge Vifquain designed is clearly influenced by the British examples. He used a wrought iron chain with eye-rods to span the 23.11 m. The main cable spans from column to column and consists of 23 chain links. The sag of the cable is low: 1 over 19. The hangers, 13 by 13 mm, are integrated in the railing. The connection between hanger and main cable is detailed very elegantly. The hybrid deck is made of iron and wood. The main beams are small iron “U” profiles (60 x 28 x 4 mm), spanning between the hangers. Parallel to the walking direction, four wooden beams, 125 mm high, carry the wooden planks (130 mm wide and 30 mm high) of the deck. The use of “U” profiles and the asymmetrical way they are bolted to the hanger let us assume that this part of the bridge has been altered in earlier times.

The tension force in the main cable is guided down via compression forces in the pillars and tension forces in the tension ties (chain links between pillar and anchorage) and the anchorage. The cast iron pillars have a “+” cross section, which was common at that time. The tension ties are built up as the main cable: they consist of four chain links. The very light and elegant appearance of the bridge refers to – what Ruddock calls – blacksmith bridges (Ruddock 1999).

The load-bearing capacity of the bridge is very low. Although the bridge is light (0.73 kN/m²), the self weight of the bridge leads already to stresses as high as 115 N/mm² in the chain and 125 N/mm² in the tension ties. In the current configuration, not the stress in the chain, but the connection between the chains is the weakest element and a live load of 0.10 kN/m² is the maximum. When ignoring the combination coefficients of 1.35 on the self weight and 1.5 on the live load, we come to a permissible live load of 0.40 kN/m². This means that a maximum of 18 people can walk on the bridge. It is hard to imagine that this number has not been exceeded in the past, even when it was in use as a private castle bridge.

But times have changed. Since 1989, the council of Kruibeke rents the castle and the park to open them to the public. As a consequence, the bridge will have to undergo much higher loads. The discussion about the acceptable load-bearing capacity of the bridge has not yet been opened, since the bridge was in such a bad condition that it was closed to the public since 1990.

Tests on the material (parts of the hanger and the railing) pointed out that the wrought iron was of very good quality so that a design stress of 200 N/mm² can be taken into account. So, when replacing the original bolts, and accepting a stress of 200 N/mm² in the tension ties, a live load of 0.85 kN/m² (or 37 people) is acceptable. Is this load high enough for a public bridge? When strengthening the tension ties, we are faced with the maximum strength of the main cable leading to a live load of 1.00 kN/m² (or 44 people). To reach a higher capacity, the main cable will have to be altered as well. As the bridge has been classified as a historical monument since 1981, the crux presents itself if this is acceptable from a historical point of view. Maybe there exist invisible methods of strengthening, or maybe the answers can be found in a limitation of access, or a reduction of the deck?

Figure 1. Side view. Iron suspension footbridge in Bazel at the castle of Wissekerke. 1824.

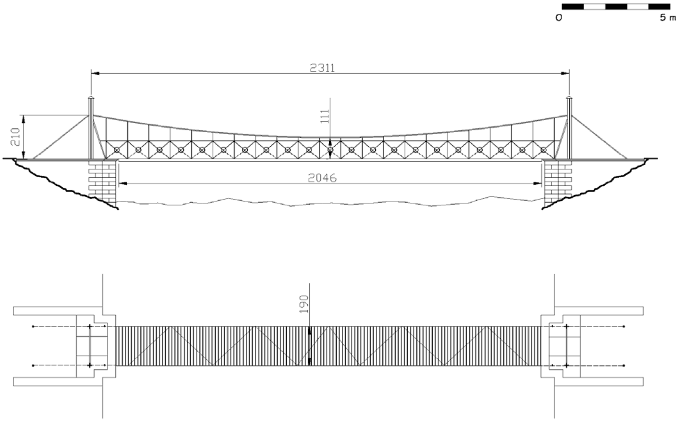

Figure 2. Plan and elevation. Iron suspension bridge in Wissekerke. 1824.

PARK BRIDGE IN ANTWERP 1869

In 1868 Antwerp decided to lay out a public park on the site of the former Spanish fortifications. The German landscape architect Frederic Eduard Keilig (1827-1895) was contacted to draw the plans for this domain of 14 hectares. Keilig created a central pond which marked the former fort moat and installed a bridge, high above ground level, to oversee the park. The rumour about the building of a suspension bridge came to the ears of La Société de John Cockerill in Seraing and, spontaneously, he sent in a proposal in April 1868. The suspension bridge he proposed was very similar to the one built in 1865 in the public park of Chaumont in Paris. His drawings show a main cable that is anchored in a rock mass. Engineer Van Bever, working in the town Antwerp, replied that the proposal was useless since there were no rocks in Antwerp. In May 1868, the final dimensions of the bridge were determined and eight contractors were asked to send in a proposal for the suspension bridge (including La Société de John Cockerill). Only two contractors responded: *Société Lucien Van der Elst et Cie (Braine-le-Compte)* for 17 500.- fr. and *Etabl. Cail et Halot et Cie (Bruxelles)* for 10 950.- fr. In July the project was assigned to Cail et Halot. In November the final plan was agreed on with completion of the bridge in May 1869. Due to a delay in the making of the iron wire cable (to be produced in Gateshead in England), the bridge was open to the public in August 1869, after being tested for 24 hours with a test load of 3.0 kN/m².

The bridge spans 27.50 m. The iron wire cable spans between two cast iron columns and has a sag of 1/10. With clamps and bolts, 17 hangers (diameter of 25 mm) are connected to the main cable. These hangers carry the 17 primary beams, which for their part carry the wooden deck. The primary beams, positioned every 1.50 m, are composed of two UPN180-profiles. The UPN-profiles are not connected to form an "I" profile, since the hanger passes in between them. Onto the iron UPN-profiles, oak beams are positioned parallel to the walking direction, on a very dense grid. Ten wooden beams, 85 mm high and 250 mm wide, are positioned next to each other with a gap of 100 mm. On top of these beams, oak planks (25 mm thick) are laid in the transverse direction. The iron strips, which serve as wind bracing are attached at the bottom flange of the UPN-profiles. The structure of the bridge deck can thus be described as hybrid since iron and wood are combined. The hollow cast iron columns are hinged at their bases and have the main cable fixed at their tops. The main cable turns into two iron strips before it enters the anchorage. Special attention has been paid to the stiffening of the bridge. The railings are designed as trusses and the main cable is placed in an oblique plan. By inclining the cables, the cross section becomes a trapezium which resists deformations better than a rectangular section.

The correspondence between engineer Van Bever and Cail et Halot reveals that the anchorages were dimensioned for a total tensile force in the cable of 400 kN. It is the construction of the masonry anchorage shaft that limits the load-bearing capacity of the bridge to a live load of 2.20 kN/m², because all the other elements (beams, hangers, main cable and columns) can stand live loads up to 5.00 kN/m².

In 1971, after a period of 100 years, the bridge was closed to the public because one of the main cables was corroded up to 50 %. Further inspection showed that there was severe corrosion on the cross beams and the railing too. The wooden deck had to be replaced. The council submitted a request for protection of the bridge as a historical monument and started the renovation. In 1976 the bridge was dismantled, the cable, railings and deck replaced.

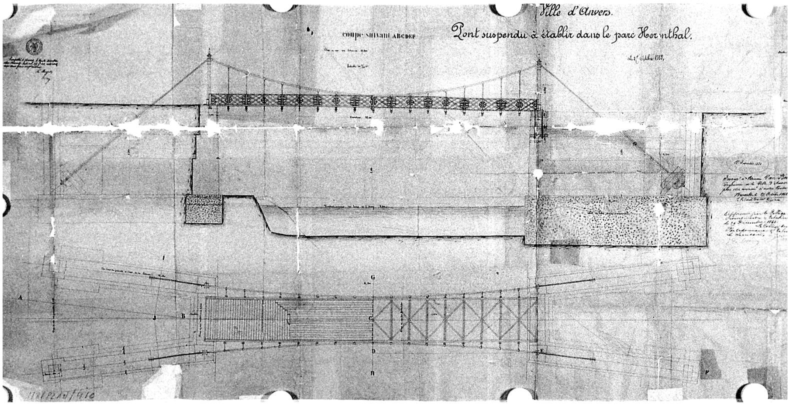

Figure 3. Original plan and elevation. Iron suspension bridge in the park at Antwerp. 1868. (Archive Antwerp).

Figure 4. Side view. Iron suspension bridge in the public park in Antwerp, 1869.

Since the bridge was originally designed to stand 3 kN/m² and since the bridge gives a very stiff and thus safe feeling when crossing it, the renovation of the bridge caused no structural problems. But still, the renovation tends more to a *rebuilding* of the bridge: the wire cable was replaced by a new steel cable (capacity 2500 kN), just like the hangers, wind bracing and anchorage bars; the double U-shaped cross beams (UPN180) changed into simple "I" shaped beams (DIN14). Only the columns and the truss in between those are still original parts.

Figure 5. Front view. Iron suspension bridge in the public park in Antwerp, 1869.

Figure 6. Front view. Iron suspension bridge at the municipal school of Zelzate, 1880-5.

PRIVATE BRIDGE IN ZELZATE 1880-5

As often happens with private bridges, not much information is available about the erection or the construction. The bridge in Zelzate is situated over a pond that once was part of the garden of a mansion. Meanwhile, the mansion has disappeared and the bridge belongs to a municipal school. If the bridge was built together with the pond, it dates back to 1880-5. The bridge spans 8.25 m and is 1.50 m wide. It is in such a bad condition that the structure is hard to recognize.

The main wire cable spans from column to column. The part between the column and anchorage is missing! The cable goes through the eyes of the hangers, which have a double function: they carry the deck and, placed every 240 mm, serve as a railing. Two beams span from bank to bank and support the wooden deck. Later on, this has been covered with a concrete plate. The iron wire cable is corroded. The abutments have subsided. The bridge is not in use.

PARK BRIDGE IN VILVOORDE 1899

At the end of the nineteenth century the council of Vilvoorde obtained a plot of 6.3 hectares. Since the domain was too swampy and unusable as building land, the council decided in 1895 to lay out a public park. In the centre of the park, a pond was created. Pedestrians could cross the pond by walking over a bridge, which hangs 3.11 m above the water surface. In 1899 the park and the bridge were built.

The bridge is 3.08 m wide and spans 17.55 m. Contrary to the previous described bridges, where the main cable consists of three parts (the main span and two anchorage cables), this cable is continuous and spans from the anchorages over the pillars. The pillars are designed as stiff towers at their bases and have saddles at their tops that permit the main cables to slide in a span-wise direction. Note that the towers are in steel and designed as trusses, built up with riveted plates and profiles. This was a logical consequence of the competitive price of steel which drove away the structural use of cast iron. At the main cable, a hanger is attached every 2.2 m, seven in total. The hangers carry the deck, which is designed as one stiff plate with primary, secondary and tertiary beams. The two primary beams (IPE180) span from bank to bank. In the transverse direction, “I” profiles (IPE100) are attached every 1.1 m. Between these IPE100–profiles, tertiary “I” profiles (IPE80) are attached every 0.77 m to carry the wooden deck. For ease of fixing the wooden deck, a small wooden plank is fixed above the IPE80-profiles. The so-formed deck is very stiff. The railing is not designed to be structural.

The original cable was already replaced in the 1970s. In 2000 the bridge has undergone a thorough renovation. The “I” profiles of the deck were badly corroded, particularly where the wind bracing was connected to the main “I” profiles, since moisture and dirt accumulated onto the gusset plates. The abutments have subsided. At this moment, the railing, the truss between the columns, the hangers and their clamps are still the original pieces. Since there are only a few hangers in this suspension bridge, they each support a large surface and the stress in their section is decisive for the load-bearing capacity of the bridge. If the stress in the hangers is restricted to 120 N/mm², the live load can attain up to 4.00 kN/m². Barriers at each side of the bridge avoid the passage of cars and motorcycles. The load-bearing capacity of this already public bridge is sufficient.

Little attention is paid to the durability of the main cable. The cable saddle cap, although drawn on the architectural plans, is not provided. The cable is in direct contact with the ground before entering into the anchorage shaft.

Figure 7. Side view. Iron suspension bridge in the public park of Vilvoorde, 1899.

Figure 8. Front view. Iron suspension bridge in the public park of Vilvoorde, 1899.

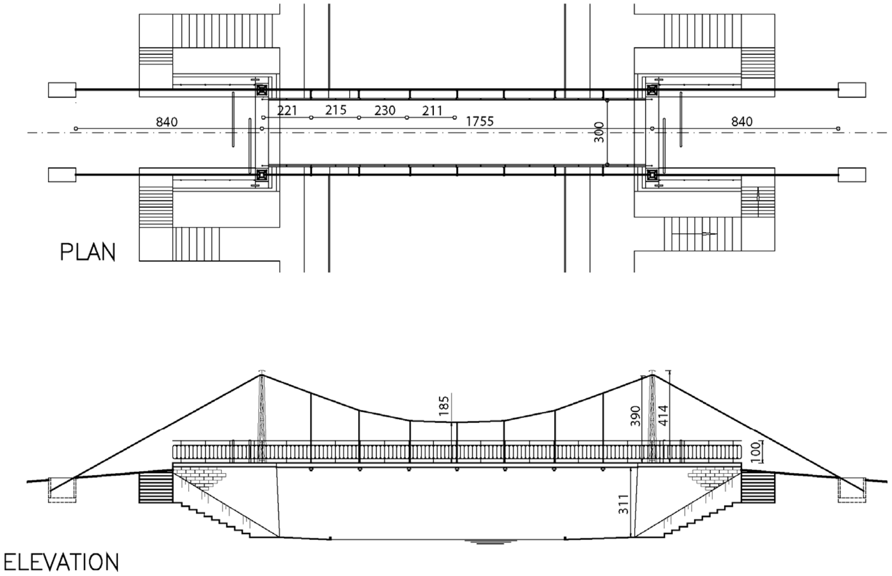

Figure 9. Plan and elevation. Iron suspension bridge in the public park of Vilvoorde, 1899.

CASTLE BRIDGE IN BEVEREN 1900-5

The suspension bridge at the castle of Cortewalle in Beveren existed already in 1905, as a postcard of the ‘Parc et Château du Comte Sénateur de Bergheyck’ shows the suspension bridge on the foreground. The plan, dating from 1900, which turns the existing park into an English garden, mentions a connection with the northern garden in the form of a bridge. Thus, probably the bridge was built between 1900-5.

Although the construction of this bridge is similar to the one in Vilvoorde, the appearance is far more elegant due to the curved deck and the ornamental railing. The bridge spans 26.37 m and is 2.40 m wide. The main cable, which is anchored in a concrete block, runs via a saddle over the top of the framed columns. The sag of the cable is 1/6 and tends to the proportions applied in America. On each cable 14 hangers are attached, every 1.75 m. The deck consists of primary, secondary and tertiary beams. Two primary curved UPN240-beams span from bank to bank. In transverse direction 14 IPN120-profiles are bolted to the primary beam. An IPN100-profile is attached between the former beams to reduce the span of the wooden planks from 2.40 m to 1.20 m. Every single plank, 150 mm wide and 65 mm high, is immediately bolted onto the main UPN-beam.

Up to 1960, the bridge served as a private bridge. In 1967 the castle and surroundings were bought by the council of Beveren who turned the site into a public space. Although the bridge was not designed as a public bridge, it can easily stand a live load of 4.00 kN/m². Nevertheless, some structural elements had to be replaced due to a lack of maintenance. In 1978, the deck of the bridge was renewed. In 1990, after one of the hangers was broken, the stability of the bridge was checked. The following renovation works were carried out: the columns were strengthened by welding new material onto them, the cable was replaced and the railing repaired. As the bridge is very lively and even one person can cause important oscillations, the railing endured serious deformations. The "design" problem of the detailing of the railing was not solved which results, today, in a deformed and buckled railing. Barriers are placed to avoid cars and motor vehicles from crossing the bridge.

Figure 10. Side view of the iron suspension bridge in Beveren, near castle Cortewalle, 1900-05.

Figure 11. Front view of the iron suspension bridge in Beveren, near castle Cortewalle, 1900-05.

Table 1. Geometries of the iron suspension footbridges.

	IRON SUSPENSION FOOTBRIDGES IN FLANDERS				
Place	Wissekerke	Antwerpen	Zelzate	Vilvoorde	Beveren
Erection	1824	1869	1880-5	1899	1900-5
Renovation	?	1971-6	-	1970s, 2000	1970, 1991
Original function	Castle bridge in English garden	Public parc bridge in English garden	Private bridge in garden	Public parc bridge in English garden	Castle bridge in English garden
Span length (m)	23.11	27.50	8.25	17.55	26.37
Width deck (m)	1.90	3.50	1.50	3.00	2.40
Main cable	Chain	Wire-cable (about 300 wires of 4 mm diameter)	Wire cable	Wire cable	Wire cable
Sag cable	1/19	1/10	1/5	1/6	1/5
Pillar	Solid ‘+’, cast iron, fixed at base, fixed chain	Hollow, cast iron, hinged at base, fixed cable	Hollow, cast iron, fixed at base, fixed cable	Portal frame with saddle	Portal frame with saddle
Number of hangers	22	17	33	7	14
Hanger	13x13mm in wrought iron	D = 25,4 mm	D =15 mm	D = 20 mm	D = 20 mm
Anchorage cable	Wrought iron 36x15mm	Double strip 75x30mm	Wire cable	Wire cable	Wire cable
Deck:					
primary	U (60x28x4)	2x UPN180	-	IPE180	UPN240
secondary	120x125 mm	125x85 mm		IPE100	IPN120
tertiary				IPE80	IPN100
Replaced elements	Deck	Cable, hanger, railing, deck	-	Cable, deck, columns	Cable, deck
Original	All elements but deck	Columns	All elements	Railing, hangers	Railing, columns, hangers
Self weight of deck	0,73 kN/m²	0,94 kN/m²	-	0,94 kN/m²	1,44 kN/m²
Permissible live load	0,1 kN/m²	2,2 kN/m²	-	4 kN/m²	4 kN/m²

CONCLUSION

Although park and castle bridges are luxurious architectural constructions, they reflect well the ongoing concerns in the history of bridge building.

As described above, the five cases show that the maintenance of the suspension footbridges is very poor nowadays. Only when wooden planks are rotten, hangers broken, abutments settled, railings bent and the main cables halfway corroded, one finds time and money for preservation works. In such circumstances, of course, most of the original elements have to be replaced by new ones.

The recalculation of the bridges shows that the live load varies from 0.10 to 4.00 kN/m². Although guidelines for the renovation of footbridges and recommendations for load-bearing capacities do not exist, these examples show that the demand of 5.00 kN/m² is exaggerated. Taking this value as a reference will lead to the loss of almost all (the original material of) historical suspension footbridges. A live load of 4.00 kN/m² has been realised for the two most recent bridges, but unfortunately at the expense of the original elements. The demand of 3.00 kN/m² is realistic and 2.00 kN/m² should be acceptable if argued.

So, it seems that not the tightened regulations, but rather the lack of maintenance causes our historic bridges to disappear. Only the most important footbridge, in Wissekerke is stuck with both threats: it is not only in a very poor condition, but the capacity of the bridge is very limited as well. Nevertheless, this bridge is of such a great importance and historical value that all means have to be used to safeguard this unique bridge.

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