# *A LINK BETWEEN GERMANY AND FRANCE THE NEW BRIDGE ON THE RHINE*

**Didier GUTH**

Arcadis

**Diter BRAET, Patrick VAN SEVEREN**

Victor Buyck Steel Construction

**Christian CREMONA**

BOUYGUES TP

## *1. INTRODUCTION*

*Work to extend Line D of the tram to Kehl, assigned by the Eurométropole de Strasbourg (EMS) to the Strasbourg Public Transport Company (CTS), started in 2014. During the first phase, the Strasbourg network will be extended by 2,7 km into Germany. The commercial service is planned to start in spring 2017. The extension into Germany is key to developing cross-border links and is planned as the future driver for urbanization in the area around the Deux Rives' district: it will allow the town to be re-centred on the Rhine. Completing the extension requires building some spectacular infrastructures, including the Rhine Bridge. Selected by the EMS and the town of Kehl, on the recommendation of the project's contracting agent, the CTS, the design and build of the structure was awarded to a consortium of businesses comprising Bouygues TPRF, Victor Buyck SC, Lingenheld TP, Früh Ingenieurbau(*), Arcadis and Marc Barani Architects, after a tendering process that took place between August and December 2012. The overall cost of the bridge, financed equally by the EMS and the town of Kehl, is €24,9M. The inauguration is planned for spring 2017.*

Figure 1 – General view of the building site

## *2. DESIGN OF THE BRIDGE*

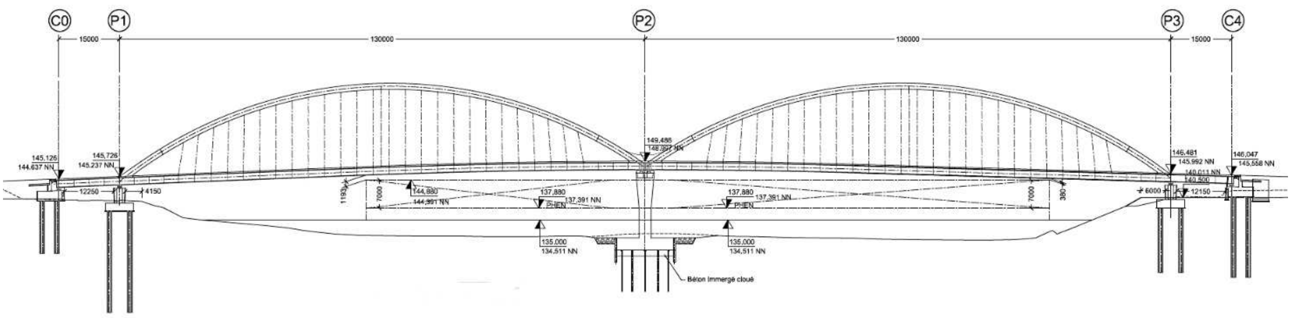


Figure 2 - Longitudinal section

## 2.1 OVERALL VIEW

*The structure is a steel tied-arch bridge, almost symmetrical, with two separate decks and four spans of 15 - 130 and 130 – 15 m (Figure 2). The structure was calculated using French Eurocodes and has been sized to carry the tram-trains that will use it in the future.*

*The static diagram (Figure 3) was determined largely by the unequal lengths of span and the constraints imposed by the railway. The imbalance in the spans (15 m/130 m) required freeing one line of bearings out of three, crosswise to each deck, to avoid the restraining of the short span generating forces that would prove significantly higher than the half-sum of the wind or seismic load. The initial idea of releasing the transverse force on the abutments was found to be incompatible with the limits imposed by the railway for the differential displacement between the deck and the abutment. Instead, the small piers (P1 and P3) support bearings that slide in both directions*.

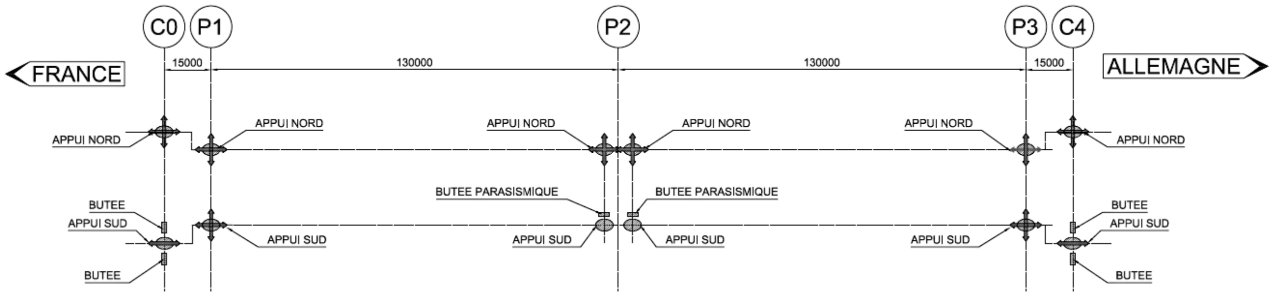


Figure 3 – Static diagram

*Longitudinally, the structure has a single fixed point per half-deck, in line with P2..*

## 2.2 THE DECK

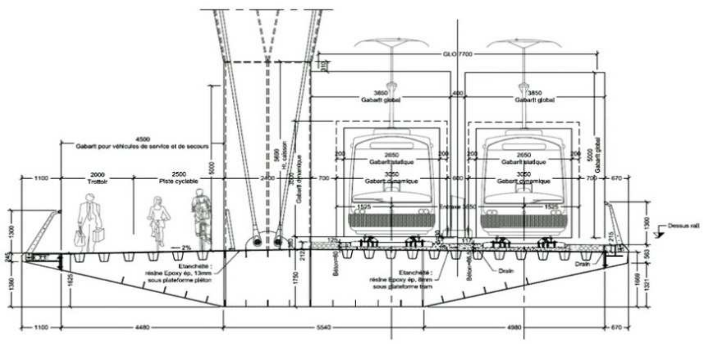

Figure 4 – Functional cross section

*The deck has an overall width of 16800 mm and is fitted with a railing equipped with LED lighting and drainage gullies covered with grating on each side. It has a 2,00 m pedestrian way and a cycle track 2,50 m wide with a separating guard rail along its length, arc-lighting units, and a concrete tram platform 8,10 m wide. The top of the deck slopes at 2% on the soft transport side and 1% on the tram side towards respectively the north and south gullies (Figure 4)*

***Structure of deck***

*The deck is an orthotropic steel box girder. Its upper deck plate is braced with box stiffeners, 6 mm-thick on the pedestrian/cycle side and 8 mm-thick on the tram side. In the 2400 mm central area between the two traffic areas, the stiffeners are flat 200x14 plates. The side faces and the lower deck plate are similarly stiffened with flat stiffeners of the same dimensions. All the stiffeners are welded to diaphragms spaced at approximately 4000 mm intervals. The upper parts of the oblique webs are braced with transverse stiffeners. The diaphragms (30 mm thick in the central section and 16 mm thick at the sides) firstly keep the box girder rigid and prevent it being distorted by transverse shear and torsion forces, and secondly transfer these forces to the hangers and hence the arches, by acting as a supporting beam for the longitudinal stiffening plates (Figure 5). One of the particular features of the structure is that the box girder forming the deck is suspended from a single arch. The arches have a rise of 20,00/130,00 or 1/6,5. They split into two approximately 5400 mm above the deck. They thus change from a single arch 2400x1500 high into two inclined arches, each 1200 x 1500 high.*

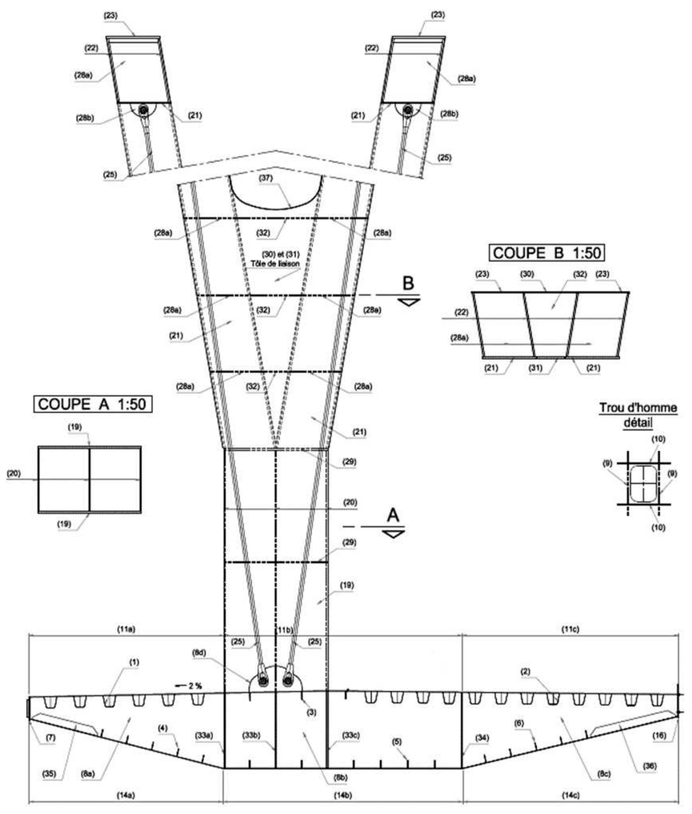


Figure 5 - Structural cross section

*Before separating, the twin arches are linked over a distance of approximately 11,00 m by plates extending their upper and lower flanges and orthogonal webs. This design reduces the arches' buckling length. The maximum free space at the top of the arches is approximately 5400 mm from girder to girder. The hangers are diameter 80 mm bars of S460 steel. They are fixed in place using a system of shackles that join them to the anchoring walls. There is a manhole in line with each diaphragm used to access and inspect the entire length of the deck. The inside of the deck is accessed via the abutments. Dehumidifiers are used to protect against internal corrosion.*

## 2.3 THE SUPPORTS

*The bridge has 4 spans and thus rests on 5 supports: abutment C0 and pier P1 on the French bank, pier P2 in the Rhine, on the French-German border, pier P3 and abutment C4 on the German bank (Figure 2).*

*Work on pier P2 started in June 2014 and finished in April 2015. The supports on the French and German sides were begun in October 2014 and January 2015 respectively. They were completed in February 2015 and April 2015.*

### *2.3.1 Supports and abutments on the banks*

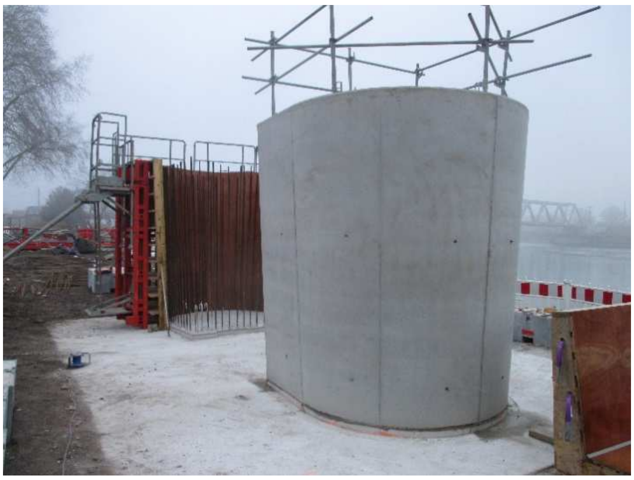

Figure 6 - Footing, pier and formwork

*The article in the journal Travaux [1] described in some detail the methods used to build the foundations, in view of the geotechnical characteristics vertically below the bearings. Deep foundations were used because of the presence of backfilling and a poor-quality alluvial layer above old alluvium. Bored piles 1200 mm in diameter with steel casings were used for abutments C0 / C4 and piers P1 / P3. An auger was used to sink 10 piles below the abutments and 6 below the piers.*

*Once the piles had been cut off, concrete slabs reinforced with 80 kg/m3 steel were poured on piers P1 and P3 (150 m3) and on C0 and C4 (250 m3). The two pier shafts were poured separately using custom-made timber formwork (Figure 6).*

*Concrete for the walls, bearings and abutments is ready-mixed C30/37 concrete prepared for exposure class XF1, based on a CEM III/A content of 350 kg/m3.*

### *2.3.2 Pier P2 in the Rhine*

*Because of the Rhine's evenly-compacted early alluvium, the design solution used a surface footing resting directly on well-compacted ground.*

*The dimensions of the footing are 18 x 14,5 m² with a thickness of 3 m. The solution chosen for the plug is a thin layer (1,5 m) of non-reinforced concrete with passive anchors (14 m long HEA 200-type) into the bed of the Rhine.*

*The cofferdam is hydraulically designed and comprises sheet piles 18,50 m long, driven 11,50 m into the bed of the Rhine. To make it stable, it was necessary to install a base of tie beams and inter-ties 10,50 m from the base of the* *excavation. The disposition of the tie beams was designed not to interfere with the formwork for pier P2. A bituminous seal was used to waterproof the sheet piles. A connection to the footing using passivated re-bars was planned so that the cofferdam could act as a cut-off trench. The pier shaft was concreted in two lifts of 7 m and 8,50 m. Rounded sections were shuttered with timber forms made in the workshop*.

*All the work involved in constructing pier P2 was facilitated by the fact that the shipping channel on the French side had been closed since work on the railway bridge located downstream of the structure (2008-2010). A floating workshop, comprising a floating pontoon, a lattice crane and a pusher boat, was used for all the work. The sheet piles were set in place and driven home using vibratory hammers.*

*The recommended layer of riprap round the perimeter of the cofferdam to avoid scouring and destabilization (5,00 m wide per 1,00 m of depth) was refilled because a 4 m hollow developed in front of the cofferdam. Heavy flooding, exceptional for the time of year, actually interrupted the work several times, and raised the flow rate in the Rhine from 1200 m3/s to 3400 m3/s. The level of the bed was measured daily, and there was no subsequent sign of this reoccurring.*

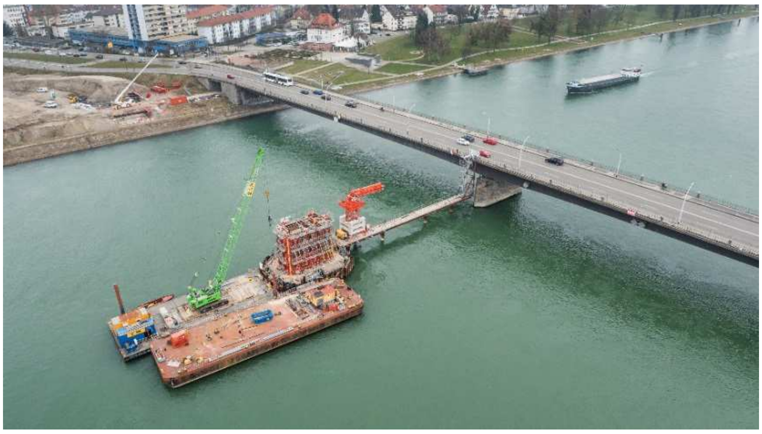

Figure 7 - Temporary boom, concreting mast and barge

*The interior of the cofferdam was regraded in order to construct the plug and the footing. In particular, it was decided to deepen the base of the excavation by at least 20 cm, to obtain the minimum thickness across the entire area. The 1,50 m-thick anchored plug was made of non-reinforced C25/30 concrete (CEM III/A content of 330 kg/m3), exposure class XC2. When the operation was complete, the hollows in the sheet piles were cleaned out by divers. A temporary boom linking the existing Pont de l'Europe to the cofferdam, with a concreting mast installed at its end, was used to convey the concrete (Figure 7).*

*It took sixteen hours to pour the concrete of the plug. The operation took place underwater, using divers to guide the concreting hose. The cofferdam was drained after 7 days, with the aim of ensuring a minimum resistance of 20 MPa. A 10 cm skin coat was installed before the reinforcing steel for the footing (Figure 8). To avoid the significant organizational problems associated with pouring concrete continuously for 20 hours at a rate of 35 m3/h, the footing in C25/30 concrete was poured in two stages (2x350 m3), spreading the concreting over two days. This meant adding 8 tons of vertical steel to withstand the horizontal forces at the point where the concreting restarted. The footing required assembling 100 tons of steel.*

Figure 8 - Pouring the concrete skin coat

Figure 9 - Reinforcing steel and first lift of pier P2.

*A setting retarder was added to the concrete mix to increase the flow time to 4 hours. Because a considerable number of heavy parts were involved, it was necessary to check that the concrete did not undergo internal sulphate reactions. These reactions are internal abnormalities that may affect cementing materials exposed to temperatures higher than around 65°C. They are caused by the delayed formation of ettringite in the hardened material, causing crystallization pressure and significant swelling. This leads to discolouration of the facing, crazing and fissuring that can accelerate the appearance of other abnormalities or reduce frost resistance. Changes to the hydration temperature were thus measured using thermocouples to check that the temperature did not exceed 75°C. The maximum temperature measured was 45 °C. Diameter 40 m steel bars 12 m long were then placed ready for the first lift for the shaft; then, once the footing had been concreted, the* *reinforcing steel and the formwork for the first section of the shaft for pier P2 were completed (Figure 9). The concrete mix is similar to that for piers P1 and P3 (C30/37 with exposure class XF1).*

*The second lift involved installing the formwork, then the peripheral skin and lastly the shear reinforcements, from bottom to top.*

## 2.4 MANUFACTURE, TRANSPORT AND ERECTION OF THE STEEL DECKS

*The bridge comprises two steel decks weighing a total of 3000 tons, including 1000 tons for the arches. Apart from the arch's springings in S460 steel, the deck was made from S355 steel. Its manufacture and erection were influenced by the transport options. Since the assembly plant at Victor Buyck Steel Construction has direct access to the waterways, the deck could be dispatched to the site by barge. Each deck could therefore be manufactured and assembled in its entire length of 145 m in Belgium. The arches were transported in 10 sections (maximum length 23,10 m). This capacity of barge transportation was a part of answering the environmental issues of the project*

***Manufacturing the deck***

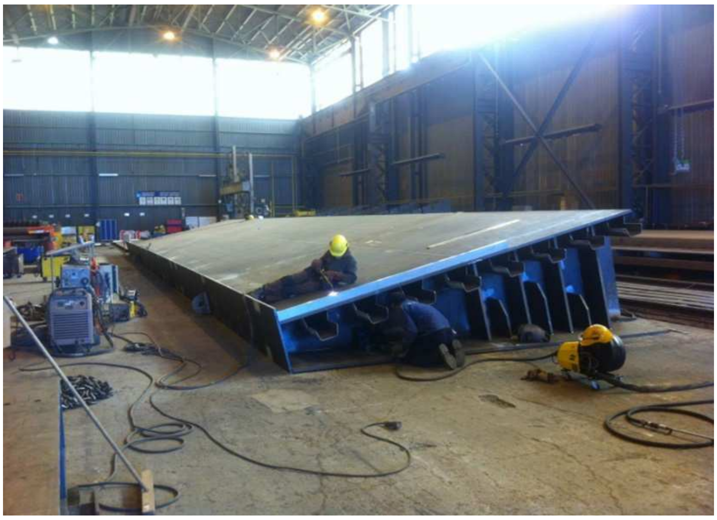

Figure 1 – Soudage en atelier

*The steel parts (apart from the hangers) were manufactured in the factories of Victor Buyck Steel Construction, in Belgium. Some parts were made at Eeklo, but the two decks were assembled in the new assembly shop at Wondelgem, located on the canal at Ghent. So that they could be assembled in two factories, each deck was manufactured in 6 sections with a maximum length of 28,50 m. Each section comprised a central box girder 5,56 m wide and 2 side box girders 4,47 m and 4,97 m wide. The sections were dispatched to Wondelgem, and then welded in a closed shop (Figure 10). The arch sections were pre-assembled in the shop in a dry run, to ensure that the on-site erection would run smoothly. Manufacture included a both a vertical and horizontal precamber, because of the central suspension and the significant imbalance in weight, as there is a concrete slab on the tram side only. An additional precamber of 125 mm, towards the bottom, was applied to each abutment to force a load on the bearings which otherwise would have tended to rise when the central span was loaded.*

***A river journey***

Figure 11- Loading the decks at Ghent

*Each deck was loaded from the workshop onto a barge using Self Propelled Modular Transporters (SPMT). Incidentally, it was necessary to spray water on one of the decks during handling, to cool it down when the spring sunshine in Belgium heated the top. This caused the deck generally to curve - a problem as there was only a small distance between the ground and the base of the deck (Figure 11). The arches were loaded using mobile cranes onto a second barge. The two barges were aligned one behind the other and towed and steered by a tug boat and a pusher boat. All the parts were conveyed by river from the workshops of Victor Buyck Steel Construction (Ghent), via the Ghent-Terneuzen canal, on to Rotterdam and then up the Rhine to the town of Strasbourg (Figure 12).*

*As the assembly area at Strasbourg was restricted in size, the deck was taken to the German side first although it was installed last.*

.

***Unloading, assembling the arches and installing the hangers***

Figure 12 - The river convoy

*In order to raise the arches to the decks and finally assemble them, they were unloaded on two separate days at Kehl, on the German bank of the Rhine, using the SPMTs, which remained on the barge during loading. The difference in height between the barge and the assembly area required a launching ramp positioned on the barge. The barge was stabilized by using ballast to balance the loads throughout the operation. The barge was steered using cables and anchor points attached to the banks*

Figure 13 - Support bents and mounting the arches

*Assembling the arches required more than 300 tons of erection equipment (Figure 13). The arch sections were placed on the erection bents by means of two mobile cranes. The tops of the bents were accessed to make adjustments and weld the arches via scaffolding that enabled VBSC staff to move around and work in complete safety. The hangers were mounted in a single length to avoid using turnbuckles, which Marc Barani considered unsightly. They were installed after the arches had been welded. They were installed after the arches had been welded. Only after the hangers had been installed were the bents dismantled. Interestingly, because of the length and flexibility of the deck without its arches and hangers, in order to raise/lower the deck on the bearings by means of a jack, more than 15 stages had to be analysed. The bents used to assemble the first deck were reused for the second*.

***Installing the decks***

*The installation took place on 7 and 18 December 2015, for the French and German decks respectively.*

*Before installing the decks in their final location, 4 vertical tie beams were erected approximately one quarter of the way along the central span. These beams were essential during the installation stages: without them, the strength and stability of the deck and hangers could not have been verified.*

*Four stages were required to install each of the decks. Each deck was*

- *brought to the correct level on the bank, i.e. the bearings were displaced vertically in parallel with the final geometry,*
- *loaded by launching it horizontally from the banks onto the barges, using SPMTs,*
- *placed on the piers and abutments by displacing the barges (Figure 14),*
- *adjusted into its final position*

Figure 14 - Aerial view of the installation of the decks © @airdiasol-Rothan

*The deck was first brought to the correct level by adjusting the jacks at the assembly area, to reduce the use of the jack once the deck was on the barges. The launching operation was used to cantilever the deck over the Rhine, then to load it on the twin barges (2 barges coupled side by side). This was accomplished using SPMTs, barges, jacks and a pusher boat. After the French and German Waterways Authorities (VNF and WSA) had, with the agreement of the Central Commission for the Navigation of the Rhine (CCNR), closed the waterways, each deck was positioned using the twin barges, steered by cables anchored to the banks and a pusher boat, in order to orient it in its final direction. There was a nasty surprise when vertical timber piles were found on the bed of the Rhine: these obstructed the traction cables, requiring divers to be sent down. The final manoeuvre was to lower the deck using jacks to bring it to its final level.*

Figure 2 - Pieux en bois au fond du Rhin

*The same installation operations were repeated for the second deck, 10 days later*.

*A bridge between two countries, especially between Germany and France, carries a lot of symbols. The new bridge over the Rhine forms part of the extension works on Strasbourg's tramway in the direction of Kehl, Germany. Once opened, this new bridge will offer users multiple means of sustainable transportation, either by tramway or bicycle, and will facilitate the efficient connection of French and German citizens.*

## 2.5 CONCLUSIONS

*A bridge between two countries, especially between Germany and France, carries a lot of symbols. The new bridge over the Rhine forms part of the extension works on Strasbourg's tramway in the direction of Kehl, Germany. Once opened, this new bridge will offer users multiple means of sustainable transportation, either by tramway or bicycle, and will facilitate the efficient connection of French and German citizens.*

| ***Main quantities*** | | |
|---|---|---|
| *Preloading* | *36 000* | *$m^3$* |
| *Piles* | *576* | *m* |
| *Concrete* | *4 300* | *$m^3$* |
| *Structural steelwork* | *3 000* | *tons* |
| *Rail track* | *620* | *m* |
| *Railing* | *1 000* | *m* |
| *Sealing* | *4 200* | *$m^2$* |

## *2.6 ACKNOWLEDGEMENTS*

*The following are thanked for their contribution:*

*Elvis DARNAULT, Project Manager, CTS – Brice L'HUILLIER, Chief Engineer, Sébastien MEYER, Head of Group and Denis ROYER, Deputy Works Director, BOUYGUES TPRF*

## *2.7 REFERENCES*

*[1] Guth D., Bort M. (2015), Ligne D du tramway de Strasbourg, Travaux, N°916, July 2015, pp. 78-84*

*(*) now Schleith GmbH Baugesellschaft*