2017 BRÜCKENSCHLAG

HEADING FOR A SERIAL UNESCO WORLD HERITAGE

Congress “Bridges in the World Heritage”

IMPRINT

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WELCOMING WORDS

PREFACE OF THE THREE GERMAN MAYORS

Dear fellow citizens, dear congress participants,

This year, the Müngsten Bridge shall celebrate its 120th anniversary! When it was completed in 1897, it was one of the largest and most impressive railway bridges in the world. To this day, it remains the highest railway bridge in Germany.

The Müngsten Bridge is considered a masterpiece of civil engineering. New technologies were applied for the very first time to overcome the challenge of bridging the Wupper. During this process, the preliminary frame-less engineering work was started from both sides so that it would meet in the middle – a milestone in engineering, which also marked the dawn of modern bridge civil engineering. At that time, the bridge was the pride of an entire nation, just as were the grand-scale arch bridges of our partners and friends from France, Italy, and Portugal.

Even today, the Müngsten Bridge remains an important traffic route in the region. Because of its construction, the distance required for traveling from Solingen to Remscheid was substantially reduced. In doing this it made a decisive contribution to the industrial development of Solingen, Remscheid, and Wuppertal. Not for nothing has it persisted as a connecting and an important identifying feature as well as a defining landmark for our region. This has also been helped by the bridge park, established as part of the 2006 Regionale programme, as will the bridge festival, which celebrates the occasion of its 120th anniversary.

Because of its outstanding construction, the Müngsten Bridge is classified as a “monument of national importance”. However, it is also of worldwide significance: Together with the two bridges “Maria Pia” and “Dom Luis I” in Portugal, the “Viaduc du Garabit” in France and the “Ponte San Michele” bridge in Italy, it reveals a continuous line of development in the construction of grand-scale steel arch bridges. It is also a stroke of unbelievable luck that all five bridges have managed to survive fully preserved until this day. For this reason, discussions have been held over the past years to nominate them jointly as a Serial Transnational Site for the UNESCO World Heritage List.

The 120th anniversary is an occasion for the cities of Solingen, Remscheid, and Wuppertal to organise a specialist conference. The aim is to determine which bridges are to be included in the UNESCO World Heritage List. It shall also assess the chances of them being nominated jointly as a Serial Transnational Site.

In addition, a close network is to be established between the various neighbouring cities of the various bridges, which shall enable and promote the required exchange of expertise and knowledge. This is precisely why we are looking forward to welcoming our guests from France, Italy, and Portugal. Our meeting is intended to be the start of a close co-operation which shall optimally support both the maintenance of these bridges and the nomination proposal.

We are particularly pleased that we have been able to win over ICOMOS Germany and TICCIH Germany as co-organisers of the conference. We also welcome the many experts from Germany and indeed the whole of Europe who shall contribute their expertise. Many thanks for your commitment!

We hope that the conference shall enjoy a great deal of success, and we are sure that the conference and the festive evening event shall provide a firm foundation to build greater friendships!

Tim Kurzbach
Mayor of Solingen

Burkhard Mast-Weisz
Mayor of Remscheid

Andreas Mucke
Mayor of Wuppertal

PREFACE ICOMOS

It is a special pleasure and honour for me to welcome you all in the name of ICOMOS Germany at the conference "Bridges in the UNESCO World Heritage" in House Müngsten, Solingen, including the thanks to all those who by their initiative succeeded to organize this first and very important working meeting: all the representatives from politics and administration in the cities' triangle of Bergisches Land (Solingen, Remscheid and Wuppertal); the government administration of Northrhine-Westfalia for accepting and forwarding the proposal of the "Post-industrial landscape of the Ruhr area" for the Federal German Tentative List of UNESCO, resulting in a suggested/recommended initiative for a "serial, transnational" World Heritage nomination for the bridge of Müngsten together with comparable European huge bridge constructions.

As it is obvious that for such a proposal a long lasting preparatory period of research was necessary, made inside the governmental offices for monuments, it should be mentioned: In 1973 already one of the Journals published by the "Landeskonservator Rheinland", (the conservator/conservation monuments' office of the Rhineland) was dedicated to the Bridge of Müngsten (in the foreword the head of the office Günther Borchers declared it a cultural monument of engineering), followed in 1975 by a second volume on "Technical Monuments in the Rhineland", where the Müngsten bridge figures under monuments of transport. All these are the result of a very hard work of our colleagues who dedicated her professional life to the history of techniques and industry – a special thanks to all of them. A couple of years ago many of them founded inside ICOMOS Germany a working group for industrial heritage conservation, which is free of any intention to compete with TICCHI (The International Committee for the Conservation of Industrial Heritage), all of the members being also active TICCIH members.

Our thanks are addressed of course also to all our German colleagues as well as to the experts from Portugal, France, and Italy, who will present the five huge-arched bridges today. The publication of the conference results will become for sure a term of reference for all the future work. Based on my experience over many years in dealing with WH nominations I have to point out the importance and necessity of a scientifically worked out research and comparative study concerning huge bridge constructions – on the global, worldwide level (see the Operational Guidelines for the WH convention) – essential for serial nominations as a justification for selection and inclusion into the serial nomination. Such a comparative study will be welcome as an up-dated version of the thematic study "Context for World Heritage Bridges", worked out by TICCIH and ICOMOS in 1996. Besides it, any functioning network between the participants – already during the preparation period of the nomination dossier – would be very important, especially a "convincing" management plan. ICOMOS always will be pleased to help in solving such problems.

I wish you a successful conference as well as a successful World Heritage Nomination!

Ass. Prof. Dr. Dr. h.c. mult. Christoph Machat
Vice-president of ICOMOS Germany
Member of the Board of ICOMOS International

International Council on Monuments and Sites
Conseil International des Monuments et des Sites
Deutsches Nationalkomitee e.V.

OPENING ADDRESS OF THE GERMAN TICCIH NATIONAL COMMITTEE

TICCIH – that is short for The International Committee for the Conservation of the Industrial Heritage – has been involved with the documentation and research on industrial heritage worldwide for over 40 years now and has been engaged in lobbying for heritage sites at risk during that whole period of time.

As a worldwide network of experts on industrial heritage, TICCIH continually supports ICOMOS committees engaged in UNESCO world heritage applications by completing thematic studies on e.g. railways, canals or collieries. Moreover, TICCIH experts continue to be engaged in the investigation and evaluation of other potential world heritage sites.

In 1996 a first study with the title „Context for World Heritage Bridges" was published by Eric DeLony, Chief of the Historic American Engineering Record, National Park Service, in the USA.

In his foreword DeLony hits the heart of the fascination of building bridges: "Bridging rivers, gorges, narrows, straits, and valleys always has played an important role in the history of human settlement. Since ancient times, bridges have been the most visible testimony of the noble craft of engineers. A bridge can be defined in many ways, but Andrea Palladio, the great 16th century Italian architect, and engineer, hit on the essence of bridge building when he said: '... bridges should befit the spirit of the community by exhibiting commodiousness, firmness, and delight.' In more practical terms, he went on to explain that the way to avoid having the bridge carried away by the violence of water was to make the bridge without fixing any posts in the water. Since the beginning of time, the goal of bridge builders has been to create as wide a span as possible which is commodious, firm, and occasionally delightful. Spanning greater distances is a distinct measure of engineering prowess."

Thanks to the support of German TICCIH members the Müngsten Railway Bridge – as well as some other bridges which will be portrayed during the conference – managed to get on the list of "potential world heritage bridges" in DeLony's study.

In the meantime, other projects such as the Firth of Forth Bridge in Scotland has been added to the world heritage list which already includes e.g. the famous bridge of Pont du Gard in France and the Iron Bridge in the UK. Outstanding repair and conservation work has now been completed to this fully operational railway bridge in Scotland, which, however, as we know, required a lot of time, energy, and financial support.

In his study, DeLony went on to say: "It is the job of TICCIH and its member countries to identify and make a case for outstanding bridges so they can be appreciated and protected like the great architectural and natural monuments already designated."

We sincerely hope that this international conference will make a significant contribution to this ambitious project. On behalf of TICCIH allow me to wish us all every success!

Norbert Tempel
Speaker TICCIH Germany /
National Representative TICCIH Germany

INTRODUCTION

THE PLANNED SERIAL NOMINATION OF FIVE GRAND-SCALE ARCH BRIDGES FOR THE UNESCO WORLD HERITAGE LIST

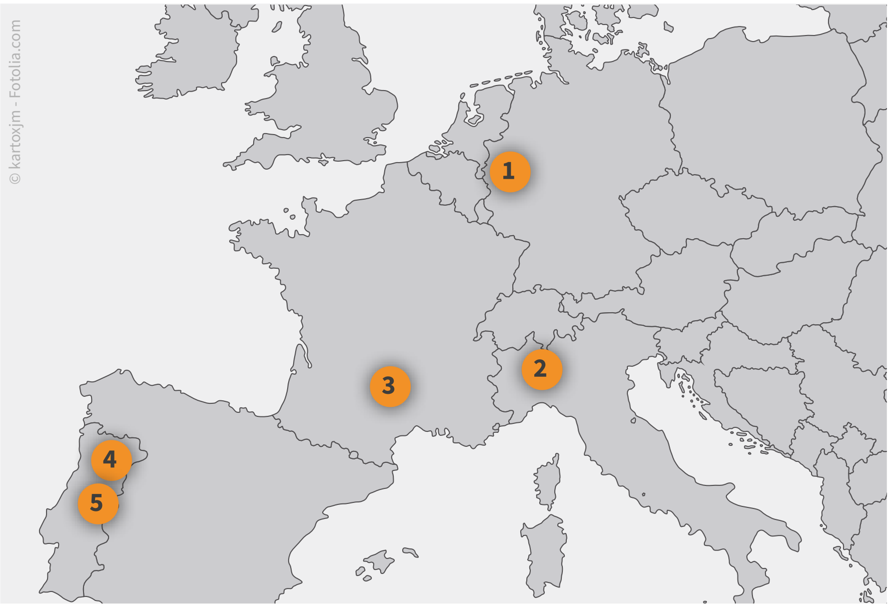
Michael Kloos and Baharak Seyedashrafi

The Convention for the Protection of the World Cultural Heritage of 1972 is based on the guiding principle that "parts of the cultural and natural heritage are of exceptional importance and must, therefore, be preserved as part of the World Heritage of all humanity." The UNESCO World Heritage List comprises the natural and cultural heritage of humanity of Outstanding Universal Value (OUV).

Serial World Heritage properties comprise various component parts which might be located in different countries. According to the Operational Guidelines for the Implementation of the World Heritage Convention, paragraph 138 b, "a serial nominated property may occur: within the territory of different States Parties, which need not be contiguous and is nominated with the consent of all States Parties concerned (serial transnational property)".

The European grand-scale arch bridges of the 19th century are a significant example of a type of building and engineering techniques developmen after the industrial revolution. Hence, the potential Outstanding Universal Value of the transnational nomination proposal "The Grand-scale Arch Bridges from the 19th Century" is expressed due to the continuous technical development represented by these types of bridges in European countries in the 19th century. In addition, the last arch bridges from this period can be preserved for future generations due to the inscription in the UNESCO-World Heritage List.

The following five European grand-scale arch bridges in the 19th century could be included in the serial nomination for the World Heritage List:



1. Müngstener Brücke (Germany)
2. Ponte San Michele (Italy)
3. Garabit Viaduct (France)
4. Ponte Maria Pia (Portugal)
5. Ponte Dom Luis I (Portugal)

fig. 1: Purposed Five European arch bridges in the 19th century for the serial nomination for the World Heritage List

Müngstener Brücke, Germany

It spans the river Wupper connecting the cities of Remscheid and Solingen. With a height of 107 m and a length of 465 m, the bridge is the highest railway bridge in Germany. It represents state-of-the-art engineering work during the Second Industrial Revolution in the late 19th century.

fig. 2: Müngstener Brücke, Solingen – Remscheid / Germany, Anton von Rieppel, 1893-1897 (© Dennis Pikarek - Fotolia.com)

Ponte San Michele, Italy

It crosses the river Adda near Milan, between Paderno d'Adda and Calusco d'Adda, in Northern Italy. This wrought iron viaduct with a double-deck structure has a span of 150 m and a height of 85 m. The bridge is a significant example of industrial architecture in Italy from the 19th century.

fig. 3: Ponte San Michele, Paderno d`Adda-Calusco d`Adda / Italy, Jules Röthlisberger, 1887-1889 (© UMB-O - Fotolia.com)

Garabit Viaduct, France

It spans the River Truyère near Ruynes-en-Margeride in France with a height of 165 m and a length of 565 m. The wrought iron viaduct is one of the most remarkable works of Gustave Eiffel which was the world's highest bridge of its time.

fig. 4: Garabit Viaduct, Ruynes-en-Margeride / France, Gustave Eiffel / Maurice Koechlin, 1880-1884 (© rochagneux - Fotolia.com)

Ponte Maria Pia, Portugal

It crosses the river Douro from Porto to Gaia, with a height of 61.20 m and a length of 563 m. The bridge has had a significant role in the history of railway bridge design and construction because the latest engineering techniques were used for constructing the central arch.

fig. 5: Ponte Maria Pia, Porto – Vila Nova de Gaia / Portugal, Gustave Eiffel / Theophile Seyrig, 1875-1877 (© Artur - Fotolia.com)

Ponte Dom Luís I, Portugal

This metal arch bridge with an upper deck for street traffic – today used for tramcars – and a low-lying deck for street traffic has the longest span of its type in the world (172 m) and at the same time displays technical and aesthetic quality.

Fig. 6: Ponte Dom Luís I, Porto – Vila Nova de Gaia / Portugal, Theophile Seyrig, 1886 (© karnizz - Fotolia.com)

The current document attempts to represent the first congress experts' working papers for the proposed serial nomination as a shared cultural heritage between these countries. The studies are intended to summarise the significant technical and historical aspects of potential serial UNESCO World Heritage nomination and their importance of preserving heritage which links the properties from different nations.

Reference

UNESCO. (1980). Convention concerning the Protection of the World Cultural and Natural Heritage: adopted by the General Conference at its seventeenth session, Paris, 16 November 1972. Paris, Unesco.

UNESCO. (2016). Operational Guidelines for the Implementations of the World Heritage Convention, WHC.16/01. 26 October 2016. Paris, Unesco

AIMS OF THE CONGRESS AND MEMORANDUM OF UNDERSTANDING

Rolf Höhmann and Michael Kloos

The Müngsten Bridge participated in a pre-Tentative List World Heritage process of the German Federal State of North Rhine-Westphalia in the year 2012. Although this first attempt was not directly successful, the advisory committee asked for deeper research into the question of bridges in the World Heritage and a possible transnational nomination for grand-scale arch bridges. Further research revealed that five 19th century large steel arch bridges in Europe can be compared and might fulfill the requirements for a serial nomination.

In this Congress, the first part will deal with the investigation and systematics of various types of bridges and their current representation in the UNESCO World Heritage List. At the same time, the Thematic Study "Context for World Heritage Bridges" published by TICCIH and ICOMOS in 1996, together with its possible supplements and updates, will also be discussed.

During the second part of the conference, the five grand-scale arch bridges will be presented and future steps with regard to a potential nomination for the UNESCO World Heritage List will be discussed.

The aim of the Congress is to develop a broader understanding of bridges in the World Heritage List, the basis for future nominations and the steps to be taken for a transnational serial approach. The aim is also to deepen the connections between the owners, the countries and cities near these bridges and to exchange experiences with those involved in their conservation and restoration.

In this context, the various involved municipalities signed the following Memorandum of Understanding during the Congress:

Memorandum of Understanding

concerning the

Joint serial transnational nomination of five grand-scale arch bridges from the 19 th century

for the **UNESCO World Heritage List**

On the initiative of the Lord Mayors of the Bergisch tri-city area of Remscheid-Solingen-Wuppertal, it is intended to present five grand-scale arch bridges from the second half of the 19th century, namely the Ponte Maria Pia and Ponte Dom Luís I (Portugal), the Garabit Viaduct (France), the Ponte San Michele (Italy), and the Müngsten Bridge (Germany), as a Serial Transnational Site for inclusion in the UNESCO World Heritage List.

The five bridges were built in a relatively short period between the years of 1877 and 1897, and are closely related to each other as regards their civil engineering. They embody the state-of-the-art of engineering knowledge of their time and even today represent masterpieces of civil engineering.

In a Europe-wide context they provide an uninterrupted illustration of the course of engineering development for this type of bridge in the 19th century. This is the potential outstanding universal value of the joint serial transnational nomination proposal. It shall also help preserve the last grand-scale arch bridges from this time for future generations.

The bridges have been connecting cities and the regions in their countries for more than a century. With this intention, the joint nomination proposal should now serve to promote and consolidate international cooperation between the various participating countries and municipalities.

The pre-condition for a potential inscription on the UNESCO World Heritage List shall be a recognition of the outstanding universal value of these five bridges. All of this must be confirmed in an international comparative analysis. In addition, the integrity and the authenticity of the five bridges must be justified, as demanded by the international Operational Guidelines for the Implementation of the World Heritage Convention. A management plan must also be elaborated that shows how the bridges can be maintained for future generations.

To this and the cities involved, including Porto, Paderno d'Adda and Calusco d'Adda, Solingen, Remscheid and Wuppertal, are all agreeing

1. to acknowledge and support the proposal to jointly nominate the above five bridges for inscription on the UNESCO World Heritage List,
2. to intensify the joint international cooperation, so that the announced international serial nomination project is founded on a solid basis in the participating municipalities and regions,
3. to do everything in their power to ensure the protection and conservation of the bridges for future generations,
4. to support the exchange of experts and expertise in order to create a suitable scientific and substantive basis for the nomination, and to support each other mutually as part of the preservation plan,
5. to draft a joint nomination dossier to justify the potential outstanding universal value of the five bridges,
6. to develop a common management system to maintain the potential outstanding universal value of the five grand-scale bridges according to the Operational Guidelines of UNESCO,
7. that within the scope of this undertaking no direct financial commitments are to arise for the local authorities related to the nomination process, although application for funding for the project shall be supported by the municipalities.

Solingen, October 29, 2017

Fig 1: The municipalities' agreement on Memorandum of Understanding (© Studio 310)

CHAPTER 1:

BRIDGES AS UNESCO WORLD HERITAGE PROPERTIES

HOW TO BECOME A WORLD HERITAGE BRIDGE: IMPORTANT LESSONS LEARNED FROM THE FORTH BRIDGE'S SUCCESSFUL NOMINATION

Miles Oglethorpe

Abstract

In 2015, The Forth Bridge was inscribed onto UNESCO's World Heritage List during the 39th session of the World Heritage Committee, held in Bonn, Germany. The nomination process had taken less than four years, and the associated documentation was praised by the World Heritage Committee for the high quality of its presentation and for its brevity.

Although the nomination seemed relatively simple, there were a number of key issues that drove the way in which it was managed and presented. Of these, one of the most important was that it is a busy operational railway bridge still performing the function for which it was originally designed. Another is that of its setting – it is an enormous structure that can be seen from many parts of Central Scotland.

These and other potential challenges were overcome, and it was with this in mind that the organisers of the Solingen World Heritage Congress invited The Forth Bridge's nomination team to share with delegates some of the lessons learned from the UNESCO process.

This paper, therefore, attempts to tackle some of the main issues that will face the partners of the proposed serial nomination of European Iron / Steel-arch Bridges in each of their four countries, based on The Forth Bridge's experience. Topics covered include working with each State Party, ensuring adequate statutory protection is in place, getting onto the Tentative Lists in each country, forming partnerships with key stakeholders, winning the support of not only the owners but also the adjacent communities, bringing the condition of the monument up to standard, engaging with the national branches of ICOMOS, managing the setting and associated potential Buffer Zones, and harvesting the best possible records from historic archive and new survey.

If all of this is achieved, then it greatly assists the production of a compelling nomination dossier and provides a vital resource from which the management of the site can be successfully achieved following inscription.

Key Words: Forth Bridge, Operational, Railway, Scotland, World Heritage, UK, UNESCO

1. Introduction

On 5th July 2015, the 39th Session of UNESCO's World Heritage Committee voted to inscribe The Forth Bridge onto the World Heritage List. Its decision brought to a conclusion almost four years of hard work by a consortium of partners led by the Scottish Government cultural agency, Historic Scotland, closely supported by another Government agency, Transport Scotland, and property owners Network Rail.

The Forth Bridge had first been put forward for World Heritage listing as a result of its inclusion on the UK's Tentative List in 1999, but the nomination was never taken forward (DCMS, 1999). In 2010, the UK Government announced that it was closing the 1999 Tentative List and invited a new tranche of candidates to be put forward. Ultimately, 38 candidate sites were proposed, and an expert panel selected eleven to be taken forward for inclusion in the new Tentative List (DCMS, 2011). Having been proposed by Fife Council, The Forth Bridge was included in the final eleven, and was subsequently selected to be the first to progress to the nomination. The Industrial Heritage team at Historic Scotland, Mark Watson and Miles Oglethorpe, were then tasked with preparing a nomination dossier, which had to be ready by December 2014. In effect, this gave them two years to complete the nomination.

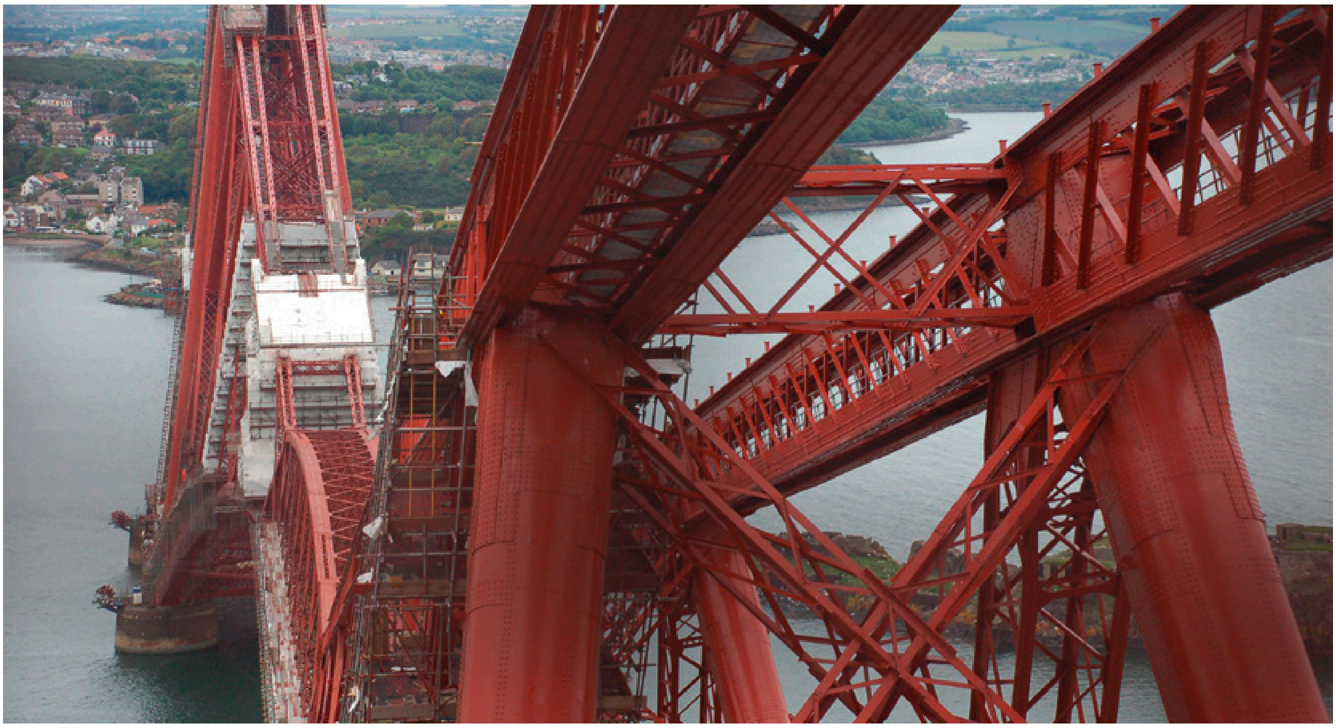


fig.1: The Forth Bridge in 2011 as the major restoration project nears its conclusion (© Miles Oglethorpe, Historic Scotland)

The nomination team had a number of major factors working in its favour. First, it had a well-recognised, iconic piece of engineering that was widely assumed to be worthy of the inscription. Second, a huge restoration scheme (Figure 1) had transformed its condition, so the timing of the nomination could not have been better. Third, the Scottish Government had recently created an umbrella body, The Forth Bridges Forum, which is responsible for co-ordinating issues relating to the Forth road and rail bridges. The Forum brings together a wide variety of stakeholders ranging from national and local authorities to tourism bodies, cultural and natural heritage institutions, and local communities. It soon became clear that the nomination should be put forward in the name of The Forth Bridges Forum. There can be few examples where a World Heritage nomination has been so fortunate – this was a 'ready-made' partnership.

Another major advantage working in favour of the nomination was the fact that it was just one entity. Many World Heritage Sites are or include significant areas with associated monuments and landscapes. By necessity, this leads to very large and complex nomination documents. For example, whilst the Old and New Towns of Edinburgh have many thousands of occupants and owner occupiers, The Forth Bridge has only one owner and no human inhabitants. There was pressure from some stakeholders to include adjacent structures (and even a bird sanctuary) in the nomination, such as the stations beyond each end of the Bridge, but the decision was taken to keep the nominated property as simple as possible. This explains why the final dossier (Forth Bridges Forum, 2014) weighed 898 grams, as compared with the tens of kilograms of some other contemporary dossiers (see Figure 2). Quite apart from keeping costs under control, it made the job of evaluation a lot less onerous, which was a winning quality for ICOMOS and its assessors.

A serious consideration for the team was that, while early World Heritage nomination dossiers were relatively simple documents, the current UNESCO operational guidance requires every Nomination Document to be accompanied by a Management Plan (UNESCO, 2017). Its purpose is to demonstrate that the key stakeholders are properly engaged, and that adequate resources and a robust organisational structure are in place to care for the nominated property, should it be inscribed. The Management Plan is therefore vital, and it follows that the larger and more complex the nomination, the less sustainable and more difficult its management and maintenance becomes.

For The Forth Bridge, it was clear that there was no need to complicate the nomination by including elements that would be difficult to manage, and for which demonstrating and protecting outstanding universal value would be a major challenge.

fig.2: The Forth Bridge nomination dossier arrives from the printers, just in time… The nomination team, Mark Watson, Marie McKee and Miles Oglethorpe (© Miles Oglethorpe, Historic Scotland)

The quest for simplicity extended beyond the property to its setting. The Forth Bridge is 2.5km long and over 100 metres high, so it is visible from large parts of Central Scotland. There were fears that the imposition of a large Buffer Zone would have a paralysing effect on planning and development and would deliver very few meaningful benefits. So, the decision was taken not to have a Buffer Zone, instead relying on an amalgam of existing natural and cultural designations referred to as the 'Bridgehead Zone'. A major advantage of this approach was that the existing designations, which protect the immediate setting of the Bridge, are statutory. In Scotland, Buffer Zones have no legal status, so in practical terms, the Bridgehead Zone provided more protection.

Inevitably, the experience of The Forth Bridge nomination has similarities with the five iron / steel-arch bridges that were being proposed for World Heritage nomination at the Solingen conference on 27-28 October 2017. It was for this reason that The Forth Bridge nomination team was invited to speak and to share its experience with delegations from the four partner countries. During the conference, the lessons that emerged fell into the categories included in the sections below.

2. Role of the National Heritage Organisation / State Party

No nomination is possible without the full co-operation of the national heritage organisation and associated culture ministry, who communicate as the 'State Party' through the permanent delegations, ensuring liaison between Member States' Governments and the UNESCO's Secretariat. In practice, all candidate sites must first be included on each country's Tentative List prior to a nomination being formally put forward. Every country's arrangements differ, and for Scotland, although culture has been devolved by the UK Government to the Scottish Government in Edinburgh, World Heritage has been reserved and must always be channelled through the UK State Party – in practice, the Department of Culture, Media and Sport (DCMS) in London.

So, any team nominating a site must first get the full co-operation and support of the national heritage agencies who combine to form the State Party. A key challenge for any serial nomination involving several different countries will be navigating through the different institutional landscapes for each candidate site.

3. Designation / Statutory Protection

In general, UNESCO understandably tries to avoid inscribing sites that are already in danger, so evaluators are unlikely to look favourably on candidate sites that do not already have the highest levels of statutory protection available in their countries. So, prior to the formal nomination process, it is essential that all component parts of any nomination are fully defined and protected by their national and local government organisations. Apart from providing a practical means of protection in the face of development pressures, it also demonstrates that the nomination is serious and based on professional standards.

The Forth Bridge is listed at Category A (the highest level of listing), and it was also possible to use several forms of both natural and cultural designation to protect its immediate setting. The amalgam of designations that formed the Bridgehead Zone included Listing Buildings, Scheduled Monuments, Conservation Areas, Designed Landscapes and historic Battlefields, together with a range of natural designations, including Ramsar sites, which were especially potent in protecting the shore areas around the property. (Forth Bridges Forum, 2014a)

4. The National Tentative List

Every country will manage its Tentative List differently and so will require a tailored approach. In the case of The Forth Bridge, the new Tentative List presented a challenge because national heritage bodies such as Historic Scotland were not permitted to propose candidate sites. One of the reasons for this was that these bodies were arbiters in the selection procedure by the 'Expert Panel' later in the process. With the deadline looming, a situation therefore evolved in which no-one had proposed the Bridge, yet Historic Scotland staff knew it had strong backing from Scottish Government ministers. Ultimately, the local authority on the north side of the Bridge, Fife Council, submitted a proposal, and it made it through into the final selection phase. This was especially appropriate because Fife Council's corporate logo comprises a graphic design incorporating The Forth Bridge.

5. Establish a Partnership Group of key Stakeholders

As stated above, the nomination team was hugely fortunate to have an existing partnership body, The Forth Bridges Forum, to work with. A Forth Bridge World Heritage Steering Group was formed as a sub-group of the main Forum, and it engaged with an even wider range of stakeholders, including local communities. This was especially important in gaining local support, and in addressing significant concerns of the communities at each end of the Bridge. The greatest worry focused on the already stretched local infrastructure – congested roads and full car parks. Indeed, there remain serious concerns about the impact of increased numbers of visitors on the communities, although there is also an expectation that enhanced tourism will bring many benefits both to the economy and potentially to the public realm.

Another crucial advantage of organising your stakeholders is that they provide the backbone around which the Management Plan can be built. One of the surprises for The Forth Bridge team was that UNESCO expects the actions contained within the Management Plan to commence before inscription, and in fact, before the formal submission of the nomination itself. This may seem a little harsh because inscription is never guaranteed, but it does demonstrate that in some cases, the process of achieving inscription brings as many benefits as the World Heritage designation itself. An important by-product of The Forth Bridge nomination has been a new website and associated brand developed by the Forum's partners (see https://www.theforthbridges.org).

6. Support of the Owners

In the UK, experienced practitioners can provide examples of early inscriptions that occurred without the knowledge or co-operation of the owners of the candidate sites, a situation that may have occurred in other countries. Today, this situation is unthinkable, but it does demonstrate the fact that now, having the support of the owners is essential. For The Forth Bridge, this was not always the case, and perhaps explains the failure to nominate over the decade following its inclusion on the 1999 Tentative List.

A major problem was the fact that Railtrack (then the infrastructure company) began to have concerns about the potential impact on the operation of the Bridge that might result from inscription. In this period, electrification programmes were being prepared, and another site on the Tentative List, Brunel's Great Western Railway, was near the front of the queue for new investment. The Great Western Railway never reached the new Tentative List in 2011, but the fears associated with its potential nomination spilled over into Scotland.

Hostility to the nomination of The Forth Bridge suddenly melted away in 2010, perhaps because of Scottish Government enthusiasm for a World Heritage listing, and since then, the new infrastructure company, Network Rail, has been hugely supportive. Another factor that may have been significant was the re-nationalisation of the railway network following catastrophic privatisation in 1997 and the subsequent Hatfield Disaster. Public ownership of the railway infrastructure certainly permits more government influence, which in turn can work in favour of World Heritage nominations. However, it is worth noting that there were periods in the 1990s when the private infrastructure company was less hostile, so private ownership should not automatically be perceived as being a barrier in its own right.

7. Condition of the Monument

Nomination teams will all wish to present their candidate sites as best as possible. Large bridges have the advantage of being visually dramatic, usually in a spectacular setting, and often being structurally iconic. The Forth Bridge is indeed one of the most spectacular and recognisable pieces of civil engineering in the world. However, if it had been nominated in 1999 immediately after its inclusion in the old Tentative List, it would not have looked good. Members of the public were complaining about pieces of 'rust' falling from the steelwork into gardens at each end of the Bridge, and it was desperately in need of new coats of paint after years of minimum maintenance. There is no doubt that an evaluation mission would have been very concerned, although health & safety surveys revealed that there was absolutely no threat to the structural integrity of the Bridge at any time.

Ultimately, public campaigns led by Professor Roland Paxton of Heriot Watt University and Tam Dalyell, a vocal and highly regarded member of parliament, persuaded the owners to embark on an enormous €160 million restoration programme. Over the next decade, all the steel work was stripped clean of its old toxic paint coverings and a new non-lead-based paint system applied. By the time of the completion of the project in 2012, the Bridge probably looked better than it had at its completion in 1890 – this was the perfect moment for a World Heritage nomination (see Figure 3).

fig.3: The Forth Bridge in 2012 after the completion of the restoration project (© Duncan Peet, Historic Scotland)

The fundamental lesson to learn here is that the best means of ensuring sufficient resources to care for and conserve a large historic metal bridge is to maintain it in operational use. Statutory health and safety requirements and engineering regulations make it imperative that it is maintained in good condition. The presence of maintenance teams also ensures that the intangible heritage associated with Bridge is nurtured. In contrast, where a Bridge has fallen into disuse, a major challenge is to find ways of bringing it back into some sort of use and with it a means of attracting revenue funding every year. Many disused British Railway bridges have achieved a renaissance by being converted into foot and bicycle paths, so a number of options might be available.

One final point is worth making in relation to The Forth Bridge experience. UNESCO and ICOMOS remain anxious that a means of measuring the impact of the maintenance regime is found. So far, it has been difficult to translate the complex data gathered during the maintenance programme by Balfour Beatty and Network Rail into a meaningful measure that chimes with conventional historic building conservation parameters and language. The World Heritage Management Group is still working on this.

8. Engage with Local Communities

Although World Heritage usually elicits enthusiasm at a national and local authority level, it often causes anxiety amongst local communities who fear negative impacts, particularly as a result of a potentially massive influx of new visitors. It is therefore essential that all nominations engage with local people and organisations, if possible winning their support or at least calming their fears.

There are many ways of achieving this. A major priority is to demonstrate the benefits that may follow inscription. For The Forth Bridge, consultant economist James Rebanks, was contracted both to identify the local, regional and national benefits, and to engage with local people and businesses. In 2009, Rebanks had produced a riposte to negative assessments of the benefits of World Heritage in the UK (Rebanks Consulting Ltd, 2009), and produced a report specifically for The Forth Bridge which provided useful content for the nomination dossier (Rebanks

Consulting Ltd, 2013). At the same time, the nomination team embarked on a public consultation the purpose of which was both to measure and influence public opinion. Such consultations can range from formal public processes launched through national government channels to cheap and highly effective initiatives disseminated via free online platforms like Google, assisted by local meetings and workshops. This was the path taken for The Forth Bridge, and public engagement was further amplified by the staging of a hugely successful photographic competition, the best entries from which were harvested and used in the nomination dossier (see Forth Bridges Forum, 2014a and 2014b).

9. National ICOMOS

The nature and organisational texture of ICOMOS varies in every country, and the idiosyncrasies can sometimes be problematic, especially where World Heritage Sites are perceived to be under threat. It is, however, extremely important to engage national ICOMOS in the nomination process, and to tap into members' expertise, which is often considerable. A key factor to consider is that it is ICOMOS International (in Paris), who are UNESCO's appointed experts, and it is they who will appoint desk-based researchers and send evaluators to assess the merits of all cultural World Heritage nominations. Their judgements are then passed onto the World Heritage Committee, so the influence of ICOMOS is hugely significant in swaying the final decision-making process.

10. Records

Without good records, it is impossible to adequately maintain, interpret or promote a World Heritage Site. As a major late 19th Century engineering project, The Forth Bridge was extraordinarily well documented both in academic papers and reports, and by the latest available forms of photography. The result is a phenomenal body of record material which provides not only the baseline data for continued maintenance, but also a rich source of publications, exhibitions and education.

Much the same situation is likely to prevail for most contemporary 19th-century bridges, so it is important to map out the historic archive and artefact collections, digitising where possible, and making them publicly available as well as incorporating the best of them into the nomination's documentation. Needless to say, many of the organisations and individuals holding valuable archives and collections are likely to be key members of any partnerships that emerge from the nomination process.

One further point is worth making. For the last ten years, digital recording technologies have evolved massively, and in particular, 3D Digital survey using laser scanners has proved especially effective in recording complex engineering sites. In the case of The Forth Bridge, the Nomination Team was able to secure Scottish Government funding that has permitted the scanning of the entire structure. In 2016, the data from over 1,400 separate laser scans was combined to create an enormous 3D model. This extraordinary resource is now being used to provide an immensely detailed and accurate baseline record, and to develop a range of educational resources for Scottish schools. The aim is to use the Bridge to promote science, technical, engineering and mathematics subjects in every primary school in Scotland.

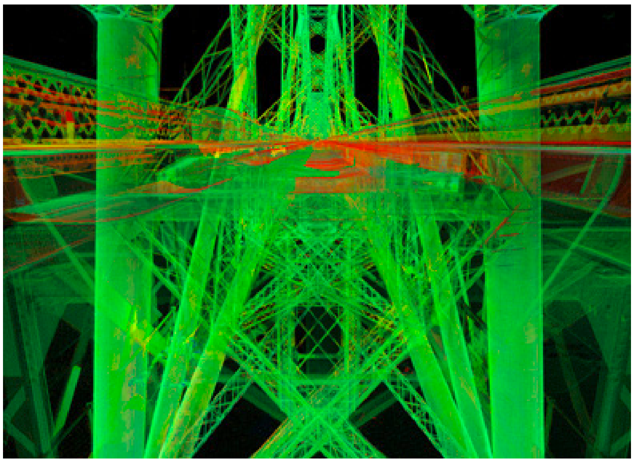


fig. 4: a point cloud derived from The Forth Bridge digital model (© Centre for Digital Documentation & Visualisation)

Just as important is that the model is being used to develop a range of 3D immersive experiences for tourism and interpretation centres. Equally significant is that digital technologies can be used to capture conventional historic archive materials such as drawings, maps and photographs, and that these can be incorporated into new digital models, creating powerful education and interpretation resources.

12. Conclusions

Perhaps the biggest lesson learned during The Forth Bridge nomination process is that 'less is more'. It is vitally important not to include unnecessary components in the nominated property, especially if there are going to be five separate bridges. Also important is the need to impose the highest level of statutory protection. In Scotland, listed-building legislation works better for operational structures, the protection provided by scheduling often being too rigid and better suited to non-functioning architectural remains.

A key factor in the success of The Forth Bridge nomination was the fact that it was and remains a busy operational railway bridge. This means that the railway company is obliged to fully fund its maintenance. If an engineering structure such as a railway bridge is no longer in use, it is much more difficult to justify expensive maintenance regimes. In these circumstances, finding an alternative use is the best option. Sometimes this is not easy, especially if public access is not safe. In such circumstances, reversible modifications should be considered. Certainly, providing pedestrian access to a historic engineering structure could create an exhilarating experience for visitors and could create a major tourism asset – something that has not yet been achieved for The Forth Bridge.

With this in mind, it might be helpful to take on the services of a consultant like James Rebanks to work with stakeholders and communities to identify and demonstrates the potential benefits of World Heritage. This work can also be integrated into the actions within Management Plans and can, therefore, be very good value.

Finally, in countries being overwhelmed by passive consumption, new generations are emerging from schools who are hugely proficient at using smartphones but are completely oblivious to the real world around them. In the UK, this is resulting the emergence of a new generation of young adults lacking in practical skills who find it difficult to find work. Schools are therefore desperately searching for ways of engaging their pupils more effectively in STEM (Science, Technical, Engineering, and Mathematics) subjects. Well-recorded, inspiring, iconic engineering structures that are inscribed onto the World Heritage List have immense educational potential – something that lies at the heart of UNESCO's core principles.

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CHAPTER 2:

THEORETICAL BACKGROUND

CATEGORIES OF BRIDGES

Burkhard Pahl

Abstract

A scientifically tenable basis of long-span structures should be discussed according to bridges structural operating principle (arch bridges, beam bridges, cable-stayed structures and movable bridges) and to the inner support structure systematics. Further distinctions are according to the material, art history aspects, location, purpose, and size. The larger the span, the lower the potential deviation from the pure structural forms.

The steel bridge designs of the 19th century are examples for the ability of the upcoming civil engineers to understand the inner structure and stands for new designs in bridges.

A rundown in chronological order is also a history of span maximisation. The most remarkable bridge structures were often those that created a milestone in terms of span at their time. In Rural Age, the essential principals (beam, arch, suspension bridges) were developed. The periods from Antiquity, Middle Ages up to Modern Age (~ 1750) were determined by the arch and the use of stones as material. Also, remarkable wooden bridges were realized. Industrial developments in the field of iron and steel facilitated the decisive step towards long-span, filigree structures. Suspension bridges have turned out to be the best-performing supporting structures for long spans (up to 2000 m span). The development of the material concrete and pre-stressed reinforced concrete bridges led to a Renaissance of beam design in bridge construction, which again underlines the achieved engineering feat.

Keywords: long-span structures, structural operating principles, arch bridges, beam bridges, cable-stayed structures, steel bridge designs, pre-stressed reinforced concrete bridges

1. About a Scientifically Tenable Basis of Long-Span Structures

Eric DeLony raised the following question in 1996: What is a World Heritage Bridge? And stated that it must: “Represent a masterpiece of human creative genius; Have exerted great influence, over a span of time or within a cultural area of the world, on developments in engineering theory, technology, construction, transportation, and communication; Be an outstanding example of a type which illustrates a significant stage in bridge engineering or technological developments.” (DeLony, 1996).

After an introduction he defines the following categories:

- Primitive bridges,
- Roman bridges,
- Bridges of Asia,
- Medieval bridges,
- Renaissance and Neo-Classic bridges,
- Wood bridges,
- Theoretical advances during the Roman and Neo-Classic period,
- Iron bridges,
- Scientific analyses of bridge design during the 19th century,
- Railroad viaducts and trestles,
- Suspension bridges,
- Steel bridges,
- Cantilever bridges,
- Reintroduction of masonry and concrete,
- Moveable and transporter bridges.

The question is whether this is a scientifically tenable basis for a classification scheme of long-span structures? What do we have? Distinction according to the material, art history aspects, location, purpose, supporting the principle and stationary/non-stationary. If we are laypersons in the field, a look into neighbouring sciences may be worthwhile. Let’s take zoology. If we want to classify the sum total of all living beings into categories, we can distinguish them into mammals, hoofed animals, domestic animals, etc.

A transfer of this approach to bridges (animals) requires us to emphasize their primary characteristic feature – namely span and the associated slenderness. Why? The larger the span, the lower the potential deviation from the pure structural form, the clearer the principle. And which principle? The load-bearing principle.

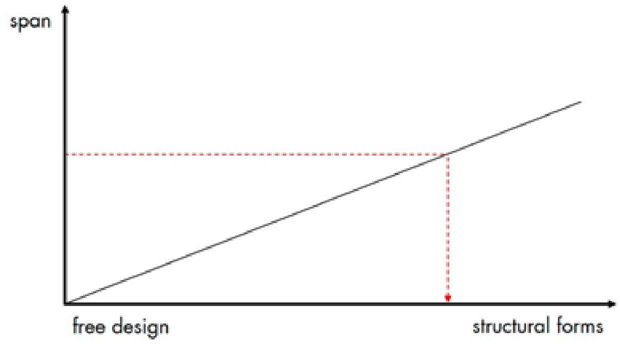

fig. 1: Relationship between span and structural (© Pahl, Burkhard IGB, University of Leipzig)

The second issue to be discussed would then be by which means (e.g. materials) the above could be achieved. Therefore, it is of interest a look at the view of civil engineers, who – since the foundation of the Ecole de Ponts et Chaussees in France, i.e. of schools of engineering in Europe – have provided scientific fundamentals and bases. In this case should be noted carefully curated exhibition and publication (Bühler, 2000) on bridge systematics and history at the Deutsches Museum in 1998. There was also a chronology table which illustrated the most significant bridge structures in their historic contexts. The systematics is basically according to a bridge's structural operating principle:

» Arch bridges,

» Beam bridges,

» Cable-stayed structures,

» Movable bridges.

The whole exhibition was inspired by a close relation to the concepts and lifework of Jörg Schlaich. The civil engineer Schlaich (Schlaich, 1992) initially considers a given long-span structure as a beam which absorbs bending forces with its cross-section.

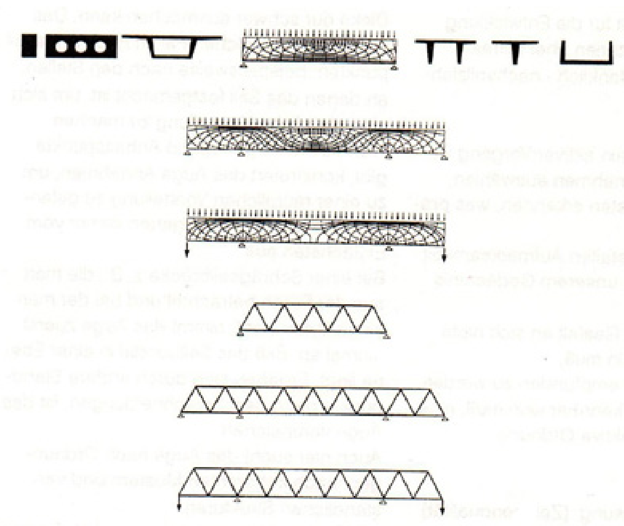

fig. 2: Systematics of Jörg Schlaich: Resolution of beam structures (© Schlaich, Jörg. sbp, Stuttgart)

Then, he dissects the cross section into its interior stress pattern to identify tension and compression zones. This consideration has given rise to a truss with a non-sway triangular geometry to optimise the beam.

In a further step, he continues to break down the beam and is confronted with the problems of slenderness and buckling stiffness, in which the stiffness can be realised by trusses and pre-stressing.

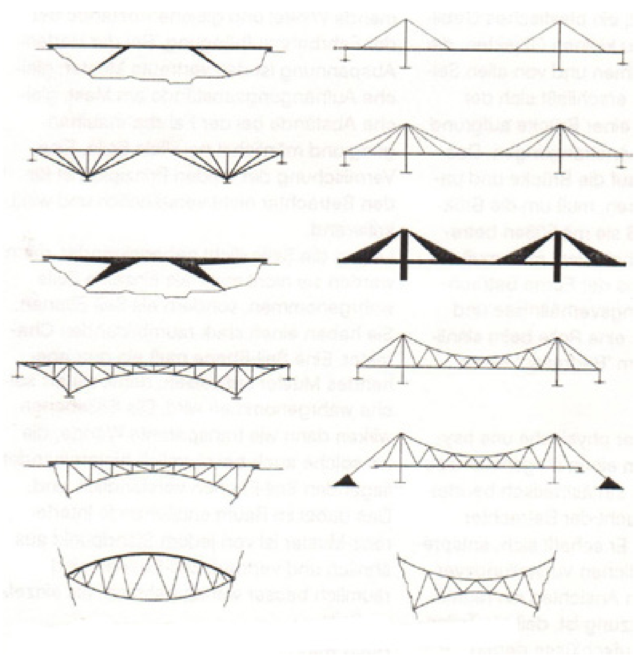

fig. 3: Systematics of Jörg Schlaich: Stiffness by use of trusses and pre-stressing (© Schlaich, Jörg. sbp, Stuttgart)

And yet another aspect comes into play. He makes a distinction between in compression-stressed structural members (arches) and tension-stressed members (cables, suspension structures).

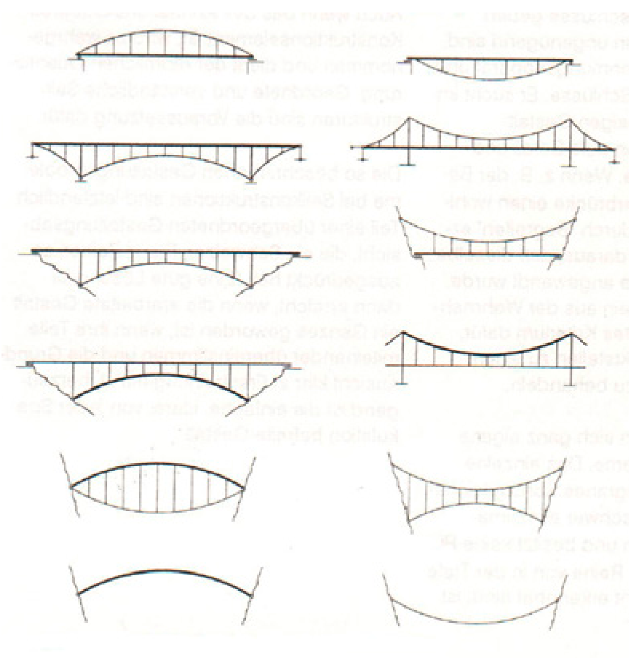

fig. 4: Systematics of Jörg Schlaich: Stiffness by use of bending and pre-stressing (© Schlaich, Jörg. sbp, Stuttgart)

This takes us to Antonio Gaudi who impressively verified and implemented arch/vault as the reversal of cables/cable meshes. Gaudi had hung up chains, lit the candles by from below, made drawings and built corresponding arches. This whole method is indeed structurally correct and was known by Leon Battista Alberti, Italy and used in modern times by Heinz Isler, Switzerland.

This brings us to H. Engel who detailed the support structure systematics even clearer. He suggests the following distinctions (Engel, 1967):

Form-active, single stress
» Cable/Arch

Vector-active
» Trusses, rod supporting structures

Bulk-active
» Flexural supporting structures, frames, beams

Surface
» Shell supporting structures

The terminology of Heino Engels finds its limits where an arched supporting structure (single stress) is dissolved into rods/trusses or a homogeneous shell (surface) into a lattice shell. This – according to its interior structural operating principle – is called by Engel a vector-active system: A rod supporting structure in the appearance of an arch.

Let us take the liberty to exercise this terminology by taking a look at the Garabit Viaduct by Eiffel, built in 1884 – in comparison to the Müngsten Bridge, completed in 1897 by Anton Rieppel/MAN. The operating principle is a rod supporting structure with pure tension and compression forces according to H. Engel. The appearance of the overall system is a steel truss, consisting of a two-hinged arch (Garabit) resp. restrained arch (Müngsten Bridge), both with elevated carriageway, the latter as a relieved beam.

Three aspects were annoying challenges to the engineers:

» The system-conditioned horizontal forces of arched supporting structures,
» The point loads of the elevation which influence the shape (polygon/parabola),
» The horizontal loads (braking loads) in the beam which may lead to a reversal of load cases (tension/compression).

The steel bridge, designs of the 19th century are examples for the ability of the upcoming civil engineers to understand the inner structure. They understood and realized retained bodies and indetermined steel structures (f. e. Müngsten Bridge), which leads to modern, reinforced concrete bridges and even to hybrid structures in our modern time.

2. Rundown in Chronological Order

The rundown in chronological order is also the history of span maximisation: Spans in Antiquity were 30 m, in the Middle Ages 50 m, in the 19th century 150-500 m, in the 20th century 500-2000 m, i.e. the most remarkable bridge structures were often those that created a milestone in terms of span at their time. So far, we can agree with DeLony.

Rural Age, Fundamentals:
- Beam
- Cantilever
- Arch
- Suspension bridge

Antiquity, Middle Ages to Modern Age:
- Block arch
- Wood bridges; Wood trusses and Truss frames

Industrial Development:
- Relief of the arch
- First suspension bridges
- Steel trusses (relieved beams)

Giants of Span:
- Suspension and cable-stayed bridges

Renaissance of the beam:
- Pre-stressed concrete

fig. 5: Chronological order (© Pahl, Burkhard IGB, University of Leipzig)

2.1 Rural Age

The beginnings reach way back into early rural lifestyles. Initially, primitive bridges were built of tree logs or stone slabs. An extension of the span was achieved by cantilever bridges two-thirds of which were typically supported and are regarded as predecessors of arch bridges. The best-performing bridges in the early days in terms of their span were built in Asia (India, Nepal) some 2500 years ago were cables were braided into suspension bridges of lengths up to 200 m. This meant that essential principles were developed that are still adopted today:

» Beam,

» Arch,

» Suspension bridges.

2.2 Antiquity, Middle Ages to Modern Age

The periods from Antiquity, Middle Ages to Modern Age (~ 1750) were determined by the arch and the use of stones as material. There were also wood bridges. The development from the 2nd century BC onwards was driven by the Romans, they mastered foundation work, vaulting technique, stone milling work, opus caementicium (precursor of concrete) also in dry construction. The Pont du Gard (France) was deemed to be extremely daring, with a span of 24.5 m and a ratio of buttress width to the span of 1:5, the usual ratio was 1:3. A typical feature was the arrangement of arches in a semi-circle in order to try and avoid a horizontal arch thrust.

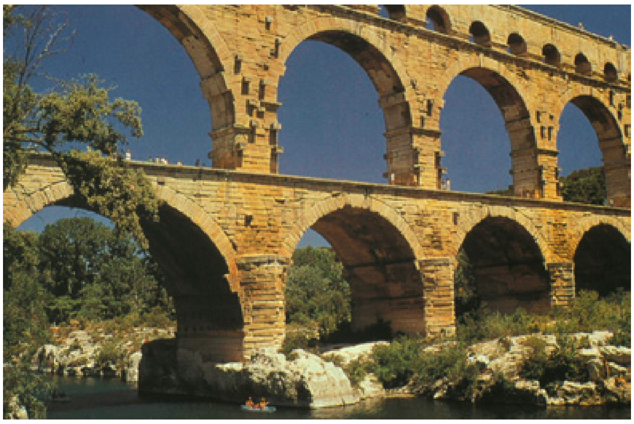

fig. 6: Pont du Gard, Nimes, about 19 B. C. until 50 (© Pahl, Burkhard IGB, University of Leipzig)

Further examples are the bridge at Alcantara, Spain, ca. 105 – 6 with 30 m span and a buttress-to-span ratio of 1:3.3. Remarkable is also the still retained Ponte Fabricio in Rome from 62 B. C. with continuous circular arches and a 26 m span. The Middle Ages were characterised by very flat arch bridges of ashlars and 20-35 m spans: Pont d´Avignon in the 12th century with 20-25 m, Ponte Vecchio in Florence from 1345 with ~ 32 m, Rialto Bridge from the Renaissance in Venice from 1591 with 27 m. Slenderness was paid for by considerable extra work in supporting areas by means of superimposed load, bridge houses, abutments, etc. (system-conditioned horizontal thrust). Bridges were of course also built in Asia, such as the 5-part Kintai Kyo arch bridge of wood from the 17th century with a total length of 194 m. Wood bridges had attained a high technological standard already in the Middle Ages, e.g. through Palladio's beam bridge across Brenta river in Bassano di Grappa, Italia around 1550 with 13 m span.

fig. 7: Brenta River Bridge, Bassano di Grappa, Italy, ~1550 (© Pahl, Burkhard IGB, University of Leipzig)

Remarkable are the outstanding bridge designs of the Grubenmann brothers, here the truss frame of their Rhein Bridge in Schaffhausen around 1750 with 61 m span. They used a technique that was borrowed from roof trusses. Wood bridges were also used as falsework structures for stone bridges. This category also includes truss-framed bridges, like the Chapel Bridge in Lucerne, Switzerland with origins in 1333. Those wooden structures became role models for the bridges built by American settlers. So-called Burr, Town, Long trusses, which basically are lattice trusses. Sensational were the so-called Howe girders that were pre-stressed with vertical steel rods and thus had an enormously high stability.

fig. 8: Howe girder system, Graubünden, Switzerland (© Pahl, Burkhard IGB, University of Leipzig)

2.3 Industrial Development

Industrial developments in the field of iron use from 1735 facilitated the decisive step towards long-span, filigree structures. The first bridges of cast iron, such as the famous 'Iron Bridge' that crosses the River Severn, England, of 1777-79 with 31 m span, were oriented on block arch bridges and inserted joint's which were known from timber construction. In structural terms, that bridge does not have an arch but two half-frames.

fig. 9: Iron Bridge, England 1777-79 (© Pahl, Burkhard IGB, University of Leipzig)

A short time later the slender bridge across Striegauer Wasser in Silesia (then in Germany) was built in 1794-97 with 13 m span with help from John Baildon, a Scottish engineer. The inserted rings already illustrate the problem of an elevated carriageway that was solved by Th. Telford in 1815 with a sensational, pre-fabricated lattice truss with 40 m span: Craigellachie Bridge across the river Spey in Scotland. Another notable pioneer of early iron bridge design was the Pont des Arts in Paris, 1801 – 03 with 18,52 m span.

fig. 10: Craigellachie Bridge, Scotland, 1815 (© Pahl, Burkhard IGB, University of Leipzig)

Around 1850 rolled steel sheets and rivets permitted new beam constructions, box-like tubes, such as for the Conwy Tubular Bridge with a span of 122 m and its successor structure Britannia Bridge across the Menai Strait with 144 m span. This leads to steel lattice girder-like Weichsel Bridge, Dirschau, 1850 – 57 by Carl Lentze with 121 m span and a lot of filigree followers like Kinzig Bridge, Offenburg 1852 – 1858. As well a lot of droll forms were developed (e. g. Pauli-, Schwedler-, Cameltruss) according to the inner structure and statical system. In the result, the age of the railroad and new infrastructure was to become determining fort the development of bridge construction and produce new typologies, such as Gerber girders. Examples are the small Main-river Street Bridge of 1866 characterised by cantilevers with suspended spans and of course the magnificent cantilever bridge across the Firth of Forth of 1882-1890 (Fowler & Baker) with two 521 m spans. The undisputed dinosaur of the history of technology.

fig. 11: Firth of Forth Bridge, Scotland, 1882 – 1890 (© Pahl, Burkhard IGB, University of Leipzig)

Seen from a historical perspective, of highly interest was the development of long-span, filigree, extremely light-weight trusses, facilitated by the use of high-tensile steels: The Maria Pia in Porto, 1875 – 77 and the Garabit Viaduct, Southern France by Eiffel from 1884 with 165 m span, the Müngsten Bridge from 1897 with 170 m span, as well the Ponte San Michele, Italy, 1887 – 89. They established a unique bridge family. A further aspect has to be mentioned: In the 19th century national steel bridgings became symbol for technological approach: “This development brought changes not only in aesthetic form, size and span, and in relationship to the landscape, but also in the way in which bridges were used to express and embody national identity” (Nicolay, 1995).

Typologically interesting and conclusive in the group of relieved arched supporting structures is the race between Bayonne Bridge New York from 1931 with 503.60 m span and Harbour Bridge in Sydney, Australia from 1932 with 503 m span. This leads to modern thinking in engineering, where the absorbing of tension forces of the arch could be solved by the stiffness of the framework or by tied arch systems, which are a so-called ‘Langerscher Balken’, in which the carriageways absorb tension forces of the arch. The thick piers are embellishments in this case.

fig. 12: Harbour Bridge, Sydney, 1932 (© Pahl, Burkhard IGB, University of Leipzig)

2.4 Giants of Span

Beside arch bridges, suspension bridges have turned out to be the best-performing supporting structures for long spans. The beginnings were made by chain bridges, which were known from the Middle Ages. The development gained momentum from 1800 onwards. Noteworthy examples include the Union Bridge crossing the river Tweed from 1820, with 136 m span and consisting of 3 load bearing chains each. (The overhead wire cable was added in 1903). Also, Thomas Telford left two remarkable testimonies to us: Conwy Suspension Bridge from 1822-26 (99 m) and the elegant Menai Strait Bridge in Wales also from 1826 with 176 m span. Bridge development, though, was to embark on a different route: Cable bridges of steel wires were based on a fundamental work by Claude Navier: “Menoire sur le ponts suspendues” (Paris 1823). Joseph Chaley built in Fribourg in Switzerland 1834 a suspension bridge across the Saane valley with 273 m span already with a truss in its parapet as stabilisation against concentrated loads. The cables consisted of 1000 wires, bundled each into up to 20 strands. The bridge stood a sensational 89 years until 1923. Further essential developments took place in the USA, besides various setbacks and personal destinies, looking at the story of Brooklyn Bridge, 1870 - 1883 by the immigrant Roebling, his son and wife. Brooklyn Bridge illustrates very well the problem of stabilisation of long-span suspension bridges. It has a span of 486 m and is a combination of suspension and a cable-stayed bridge.

fig. 13: Brooklyn Bridge, N. Y. 1883 (© Pahl, Burkhard IGB, University of Leipzig)

The length of 1000 m was exceeded in 1931 by George Washington Bridge in New York with 1067 m (Golden Gate Bridge, S. F., followed in 1933 with 1230 m). Remarkable are the pylons of George Washington Bridge. They were never cladded. This bridge also represents – besides economic pressure - a new understanding of technology, the omission of any décor, which had been a hallmark of bridges for centuries. The retrospectively installed truss girder with two levels has a height of 8.8 m. The resulting slenderness is 1:90. A trial with a slenderness of 1:350 for a suspension bridge failed in 1949: Takoma Bridge with a length of 853 m, USA, had built up vibrations due to resonance vibrations and a missing carriageway box. The collapse of the bridge was filmed and made a severe impact on the structure of later long-span bridges. Several engineers have failed to understand this problem to date (think of the Millennium Bridge in London in front of the Tate Modern). What were the consequences? Aerodynamic profiles, diagonal cable routing and inclined tension cable routing as at Theodor Heuss Bridge 1958 in Düsseldorf, Germany with a 280 m span. In place, the carriageway beam is stabilised by the cables and horizontal forces are absorbed by the carriageway. Cable-stayed bridges are very efficient for medium spans of 300-900 m (e. g. Normandy Bridge, from 1995, with 856 m). The current performance limit of cable-type pre-stressed bridges is 2000 m. Great Belt Bridge in Denmark with 1624 m, Honshu Bridge in Japan from 1998 with its 1991 m falls just short of 2000 m, which is owed to the humility of Japanese engineers.

2.5 Renaissance of the Beam

The material concrete led to a renaissance of the beam in bridge design from around 1900 onwards. Pioneers like Robert Maillart built splendid, slender bridges, some of which can still be admired today.

fig. 14: Salginatobel Bridge, Graubünden, Switzerland (© Pahl, Burkhard IGB, University of Leipzig)

The extremely flat Salginatobel Bridge in Graubünden, Switzerland, from 1930 with 90 m span was therefore proposed in December 2016 by the Swiss Federal Council for the UNESCO World Heritage List. Another milestone was the development of pre-stressed reinforced concrete bridges with inside cables, so-called pre-stressed concrete bridges, here designed and implemented by Freyssinet between 1946-59 with spans up to 73 m. Six such bridges were built in France at river Marne. Already in the 1960s, the technology has matured to such standards that spans of 150-200 m were attained. Possibly the most eminent pre-stressed concrete beam structure is Kocher Valley Viaduct in Geislingen, Germany, 1123 m long, 185 m high, individual spans 138 m. And in modern attitude to Müngsten Bridge: Reichenau Bridge, Graubünden, Switzerland, of 100 m span, a modern pre-stressed reinforced concrete bridge, a filigree arch with elevated carriageway, was built with a wonderful wooden falsework structure in 1964 by Christian Menn.

Finally, noteworthy are three outstanding reinforced concrete bridges:

- Kylesku Bridge in Scotland by Ove Arup, a unique engineering feat of a distinctively curved concrete box girder bridge in a unique countryside, longest span 79 m, 1982 – 84.
- Ganter Bridge by Christian Menn along Simplon Pass road in canton of Valais in Switzerland with 127 – 174 – 127 m spans and stressing tendons sheathed in concrete on top of carriageway box, 1976 – 80.
- Sunniberg Bridge near Klosters in Switzerland with exposed stressing tendons. Also designed by Christian Menn with 58 up to 140 m span.

fig. 15: Sunniberg Bridge, Klosters, 1996 – 98 (© Pahl, Burkhard IGB, University of Leipzig)

All 3 bridges are curved, i.e. radial, which again underlines the achieved engineering feat.

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BRIDGES IN THE WORLD HERITAGE: NOMINATIONS, LISTINGS AND PROPOSALS OF BRIDGES IN THE WORLD HERITAGE LIST

THE THEMATIC REPORT BY TICCIH: WORLD HERITAGE BRIDGES

Rolf Höhmann

Abstract

The nomination of World Heritage Sites follows a specific process and schedule laid down in the Operational Guidelines of the UNESCO. New nominations should be part of the "Filling the Gaps"- program and relying on Thematic Studies, if available. Bridges were the theme of a Thematic Study prepared in 1996 by Eric DeLony, a member of TICCIH. This thorough statement helped in some nominations of bridges but might be revised and renewed after more than 20 years of use. To make things simpler and clearer, a reduction in bridge categories is presented here.

On the basis of the bridges list prepared by Eric DeLony, bridges inscribed as World Heritage Sites and nominations on the Tentative Lists of state parties are described, categorized and partly evaluated. The conclusion gives hints for future nominations out of the viewpoint of the author.

"Filling the Gaps", an Important ICOMOS Paper

One of the important bases for current and future World Heritage nominations is the publication "Filling the Gaps – An Action Plan for the Future" from 2004, where ICOMOS analysed the distribution of World Heritage Sites regarding the eras, the areas, the categories, meanings and conservation of already listed World Heritage Sites. As an obvious result, the study revealed that European and North American heritage was widely overrepresented, as were imperial and Christian architecture, medieval European town centers e.a. A more balanced approach should, therefore, include more nominations outside Europe, preferable from Africa, more modern heritage, cultural routes and technical monuments, at best also correcting the uneven geographical distribution.

1. Listed Bridges: Ancient and Early Modern Times

Analysing the current representation of bridges in the World Heritage List, regarding eras when they were built and in which areas of the world, we might get the impression that Roman aqueducts around the Mediterranean Sea are already featured in many examples. They are inscribed either as single sites, like the Pont du Gard in France or as elements of a serial nomination in a larger context like in Segovia, Merida, and Tarragona in Spain. The water system supplying Carthago, including another roman aqueduct, is on the Tentative List of Tunisia. The Roman engineers developed the already familiar arch construction to a high standard, using materials like natural or artificial stone and predecessors of today's concrete. This construction type was of course adopted in other regions and later eras, documented by the two World Heritage bridges in Visegrad (Mehmed Pasa Sokolovic Bridge) and in Mostar in Bosnia and Hercegovina. Both are documents and heritage of the Ottoman rule in the Balkans dating from the 15th and 16th century. The eleven arches of the Visegrad bridge and the single high arch of the Mostar bridge follow the classic design of the half-round arch but show also a pointed peak which is typical for this bridge type in Arab countries. The authenticity of both bridges may be doubtful because they were destroyed in the Second World War (Visegrad) and in the Yugoslavian civil war (Mostar, 1990), but their immaterial value as symbols of unity of different ethnic groups cannot be questioned.

fig. 1: The roman Agueducto de los Milagros in Merida, built ca. 1st century B.C. (© Rolf Höhmann)

Contemporary to these examples is the giant Padre Tembleque aqueduct in Mexico, built by a Spanish priest following roman typology, but using local adobe materials. Although designed by a European, the bridge is a rare infrastructure example in the World Heritage List outside of Europe and North America and combines European and local techniques.

2. Industrialization and Modern Bridges

The material iron marks the start of modern times and of the Industrial Revolution. One of the hallmarks of this development is the first bridge made out of cast iron in 1779, appropriately named Ironbridge. Its construction tries to imitate the well-known stone arch bridge, but its new material demanded new engineering techniques for smelting and joining the components. The bridge is set into the larger area of the Severn Valley pioneer early industrial development. Pontcysyllte Aqueduct as a further development, combining an arch and girder structure into a very unusual canal bridge was built in 1805. Forth Bridge is one of the largest bridges using the cantilever principles, enabling the largest span of its time for a double track railway and is one of the highlights of British engineering of its time. Much smaller, but equally outstanding is the Puente de Vizcaya transporter bridge in Bilbao in Spain, the first of this kind of special engineering for a special situation. As a combined Spanish-French project, it combines a Spanish invention with the French engineering skills in designing and building of cable-stayed/suspension bridges.

fig. 2: The first iron bridge in the world (© Rolf Höhmann)

Not as a single site but inscribed into the World Natural Heritage site of the Zambesi River area in Zambia and Zimbabwe is the Victoria Falls Bridge. This arch bridge was inaugurated in 1903 and is a rare example of a WH technical monument in Africa.

3. Tentative list nominations

If we look at bridges designated as Tentative List proposals for WH, the distribution in areas becomes wider. Asia is well represented, besides other countries, by 56 tentative proposals of the Islamic Republic of Iran. One of these items holds the insignificant title "The Collection of Historical Bridges". The Outstanding Universal Value is described in the UNESCO database: "Lorestan (-Province) collection of sixty historical bridges is the world most ancient and greatest over the time. Huge piles, tall arches, sizeable stones, well-ordered joints, exact water breakers, leaded fastenings, carved stones, little mortar, a vast view, beautiful recreation centers, spacious rooms, quadrangular ceilings, staircases with different uses all gathered in a bridge." These stone arch bridges of different construction outline, age, and conservation status are magnificent examples of the bridge builders' art only paralleled by the roman developments. On the comparable long Tentative List of Turkey, two single bridges are nominated: The Malabadi bridge in south-eastern Turkey has a single span and was built in 1154. It strongly resembles the Mostar bridge and might have been a model for this. The Uzunköprü bridge in the European part of Turkey is one of the longest historic bridges with a length of 1400 meters, built between 1427 and 1443. It is still in use and can be compared with the younger Visegrad bridge.

Three bridges from modern times are included in the Tentative Lists of Columbia, Chile and the United States. The Puente del Occidente in Colombia is a combined cable-stayed and suspension bridge following European examples and especially that of the Brooklyn Bridge in New York, as one of the engineers responsible worked there before during its construction. When it was opened in 1895 its 291 meters span was the largest in South America and still is the third longest. The cables are supported by four towers, which are most unusually built of wood. Malleco Viaduct in Chile opened in 1890, at this time it was claimed to be the highest railway bridge in the world with 102 meters above river level (Garabit Viaduct from 1888 is 122 meters high). The total length is 347,5 meters, the span sections are 69,5 meters long. The rigid beam bridge of the Howe type was prefabricated in iron by the French company Schneider in Le Creusot and delivered to Chile. It was later stiffened with steel cantilevers.

fig. 3: Garabit Viaduct (© Rolf Höhmann)

Both bridges show the influence of European and North American engineering in building infrastructures in other regions of the world. They show also a typical problem of the "Filling the Gaps" approach of UNESCO and ICOMOS: Technical and Industrial monuments were developed in the early industrialized nations, starting with the industrial revolution in Great Britain and then spreading to the European continent and to North America. Outstanding universal value, concentrating on "firsts", "largest", "revolutionary" and universal as a model will mostly be found in these countries, but the two South American examples are at least outstanding representing their large region and continent and are therefore of high value for further discussions.

Brooklyn Bridge is undoubtedly one of outstanding and universal value – combining American entrepreneurship in the family business of the Roeblings, with European ancestry, and the adaption and refining of European techniques in the grander scale of the fast developing American nation and their industry. Although principles of the combined cable-stay and suspension bridge had already been used in other parts of the world, namely in France, Roebling and his competitor Ellet built bridges in much larger dimensions. Brooklyn bridges universal contribution lies also in the mechanization of the wire spinning and the use of giant caissons.

4. Thematic Studies

Thematic studies are an important tool to choose and evaluate future World Heritage Sites. In the areas of the Technical and Industrial Heritage ICOMOS and TICCIH have prepared several studies: ICOMOS on the subject of the Cultural Heritage of Water (with the focus on the Maghreb and Middle East region), TICCIH on workers villages, canals, railways, collieries, textile sites, quarrying and World Heritage Bridges, published in 1996 by Eric DeLony. This was fundamental for discussions about nominations. Twenty years later we might allow ourselves to look at the results of this work and may discuss a revision and further development of the systematic and the lists included.

Thematic studies by ICOMOS and TICCIH are works of volunteer engagement, as both associations are NGOs with little financial support by state parties and mostly relying on the receipts gained by the small membership fees. To develop worldwide surveys of historical important objects and sites the collaboration of members of these associations is needed and the volunteer commitment of at least one organiser and writer is absolutely necessary.

Longtime TICCIH-member Eric DeLony was the best choice for this task. His profile as a researcher of the development of early American bridges and his long-time engagement with HAER, the Historic American Engineering Record, was an invaluable background for the data collection and the evaluation of bridges worldwide. The exchange of information was supported by several TICCIH-conferences and experts from the USA, Europe and Japan.

Eric made his own choice of important bridges and used his own systematic approach. The fulfilment of the Outstanding Universal Value, the major point for a World Heritage, was described as a function of age, material, use and/or structure types. In his list of 120 potential WH bridges, he added categories like iron, railway (which, for example, were built in all listed types), suspension, steel, cantilever and moveable bridges. It is obvious that categories like era, area, material and structure type are heavily intertwined, which makes the list somehow difficult to understand and seems to obstruct a clearer choice of bridges with high potential Universal Value, although the list gives a very good scientific base.

Regarding World Heritage today it becomes clear that only a limited number of bridges might qualify for new inscriptions. To underline choices and evaluations to be made there is one solution: make it simpler. Material and structure types are the most important factors in bridge construction. Fundamental structure types are relatively small in number, although there are many mixed types. A simplified approach could be using the five basic types for listing, arranged with the building dates in a chronological manner.

The question of materials might also be answered in a simplified approach: in early times available were stones for structures with heavy compression like the arch and wood for beams with limited length. Iron could substitute stone as cast iron, while steel could be used to fabricate beams and girders of much larger dimensions. Steel wire which can withstand extremely heavy tensions enabled the construction of the longest spans in suspension and cable-stay bridges and also made the prestressed concrete bridge a successful competitor.

The choice of examples from Eric's list in this article is neither scientific nor representative but follows personal judgements and experiences from World Heritage projects.

The five basic bridge construction types:

1. Arch
2. Beam, Truss, and Girder
3. Cantilever
4. Suspension
5. Moveable and Transporter Bridges

1. Arch

Without the doubt, the tried and proven arch, used since several millennia, is the most widespread bridge construction type and already well represented in the WHL and in tentative list proposals. Arches could be built with materials which can take only pressure like the nearly everywhere available natural stone or with artificial stone-like bricks and adobe. The art of building early arch bridges lies in the calculation, the craftsmanship and the use of scaffolding to support the during construction. Many early stone arches could survive because of their rigidity and their heavy mass. The non-existence of proper static calculations led to oversized dimensions and safety.

Following these early examples, particularly those from Roman times, many bridges were often rebuilt in early modern times on the same place and in the same techniques, like the "Roman" bridge in Merida in Spain and the old bridge from 1135 over the Danube in Regensburg in Germany, both part of larger World Heritage Sites and areas. Remains of the Teufelsbrücke ("Devils Bridge") on the old Gotthard trail from 1559 survive, substituted by an 1830 bridge.

The advent of the new material cast iron, mass-produced in coke blast furnaces, led to the construction of the first iron bridge in the Severn Valley 1779 and, besides others, the Pontcysyllte Aqueduct in 1805, both still influenced by the traditional arch. The refinement of iron to steel production, combined with rolling of profiles and riveting allowed the development of grand-scale arch bridge in the 19th century, with the five prominent examples discussed in this conference.

Eric DeLony also listed some newer 20th-century arch bridges: Hell Gate Bridge from 1912, Bayonne Bridge in New York from 1931 and Sydney Harbour Bridge from 1932. The Sydney bridge is, like the neighbouring World Heritage Opera House, one of the symbolic structures of Australia. One can wonder why they were not nominated together for the WHL.

fig. 4: The Alcantara Bridge (ca. 105 AC) in western Spain shows the classic outlines of a roman arch bridge (© Rolf Höhmann)

2. Beam, Truss, and Girder

The development of longer beams and girders was influenced by two major inventions, the mass production of steel profiles, sheets and wires and the combination of elements which could withstand high pressure like wood and cast iron and fabricated structures, while higher tensions were taken over by steel wires and tie rods. Rigid beams and trusses were first built as closed rectangular tubes by Stephenson in the Menai and Conwy tubular bridges in 1848. While the Menai spans were destroyed in a fire, the Conwy railway bridge is still in use. Following only three years later was the Dirschau (polish: Tczew) railway bridge over the Vistula in former Prussia and today's Poland.

It showed some refinements, particularly the disintegration of the solid sheet walls of the Conwy bridge into an iron (steel) lattice girder scheme. This type of girder was already in use in the United States made out of wood planks and steel tension rods. Several bridge truss types were developed by scientific and trial and error methods. In the US the fast advancement of railways and roads to the west asked for the building of bridges using cheap and local available materials, like wood, while the connections were made out of iron and steel bolts and rods which could be transported easily. Successful inventors and patentee holders in the middle of the 19th century were Fink, Whipple, Bollmann, and Warren. The designs could easily be adapted for full steel construction. The Warren truss is still the most economical and simple type and in use and built until today. Eric DeLony was engaged in the survey of the surviving bridges from this era, and at least one sample from all types could be preserved. This family of bridges deserves Outstanding Universal Value.

fig. 5: Menai Suspension Bridge by Thomas Telford 1826 (© Rolf Höhmann)

fig. 6: The original part of the Dirschau lattice-girder bridge from 1851 (© Rolf Höhmann)

Contemporary British examples still showed a tendency to individual design and extensive use of material, exemplified by Stephenson's High-Level Bridge in Newcastle from 1849 and Brunel's Saltash Bridge from 1859. Both structures show a mix of two basic types: arch and rigid truss.

Continental truss bridge design in France and Germany was influenced by better calculation methods and rational outlay, always with the goal to spare expensive iron and steel material. Some designs like Schwedlers truss were highly sophisticated. A rare example of an early German bridge in a combined lattice-girder and diagonal truss construction is the Griethausen bridge near the lower Rhine, built in 1865 with a 100 meters long span. It is out of use since the Second World War and without maintenance for more than 70 years, but the puddling steel helped its survival without any corrosion protection.

3. Cantilever Bridges

The cantilever bridge developed from wooden bridges in Asia and from the so-called false cupolas. Iron and steel girders could easily be built to project over the abutments and support suspended, shorter bridge trusses. The German engineer Gerber built the first larger wrought iron bridge in Hassfurt over the Main river in 1864 and took a patent on this construction type two years later. Its advantages at this time were easier static calculations resulting in a lighter construction sparing material. While the Hassfurt bridge was destroyed, the 1889 Poughkeepsie railway bridge over the Hudson in New York State is still in use for pedestrian traffic.

The cantilever principle became best known and represented with the Forth Railway Bridge, listed as World Heritage in 2015. Built in 1890, it holds the record span of 521 meters, in combining the length of the two cantilever arms and of the suspended span. Its rigid looks and obvious stability were a direct consequence of the Tay bridge disaster 1897 and introduced more careful calculations of wind stresses and dynamics in bridge design.

The Quebec Bridge over the Saint Lawrence River in Canada followed the design of the Forth Bridge closely but has only two cantilever towers instead of three. The longest span distance is 549 meters, again a world record between its inauguration in 1917 and 1929, but it is still the largest cantilever.

The long erection time from 1902 to 1917 was the result of two major failures. In 1907 the first cantilever tower collapsed, the reason being miscalculations. After scrapping, the remains of a total new modified structure was built. The suspended 5000 tons middle girder fell into the river in 1916 during lifting due to an inadequate bearing. A new girder was constructed and the bridge finally opened in 1919.

fig. 7: Forth Railway Bridge at night (© Rolf Höhmann)

Nearly at the same time, the largest cantilever bridge on the European continent was planned and built. The design of the Viaduc du Viaur was the result of a competition between the French engineers Eiffel, well known for many outstanding structures, and Bodin from the Batignolles company. The latter designed and built a symmetrical bridge with two identical double cantilever arms connected by horizontal pivots in the middle and on the abutments, forming a three-hinged arch. The railway bridge was inaugurated in 1902, has a span of 220 meters and is one of the three most important historical steel structures in France besides the Eiffel Tower and the Garabit viaduct.

4. Suspension Bridges

Suspension bridges were built in China at least from the 3rd Century BC onwards, using ropes made from natural fibers or hand-made wrought iron chains. The knowledge of this structure type and the techniques used came to Europe since the 17th century by travelers visiting China, as can be seen in several drawings of "chain bridges".

British engineers built several suspension bridges of this type in the early 19th century like those over the Menai and Conwy straits in 1818 and 1826 by Thomas Telford. The building of Brunel's high-level Clifton Suspension bridge started in 1836 but was finished only after his death in 1864. The British examples used wrought-iron chains which could be produced by the British industry in sufficient quantities.

fig. 8: Telford´s Conwy Suspension Bridge (1818) on the left, Stephenson´s Conwy Tubular Bridge (1848) on the right (© Rolf Höhmann)

The base for the real breakthrough for suspension bridges was nevertheless developed in France. Marc Seguin and his brothers made first trials in Annonay in 1822 to substitute the heavy chains with wire capable to take high tension loads. Their first bridge was erected in Geneva with the help of Swiss engineer Henri Dufour, who was also responsible for refinements and the erection procedure. A larger wire cable bridge was built in Tournon over the Rhone river in 1825, which was followed by a second, still existing bridge in 1847. Theoretical foundations and calculations for this type of bridge and the material used came from French mathematic and physician Navier. Over 300 wire cable suspension bridges were constructed in France in the 19th century, but none of these survived in original condition.

The successor of the Seguin brothers company was Ferdinand Arnodin, who built several suspension bridges after the system patented by Albert Gisclard. This was a mixture of suspension and cable-stayed systems, also used by Roebling and others. The Pont Gisclard bridge in the Pyrenees and the Viaduc de Rochers Noir in central France from 1908 and 1911, both built for light railways, still, exist.

Suspension bridges on a much larger scale were constructed in the US, mainly by the two competitors Charles Ellet Jr. and John A. Roebling. Still in use is Ellet´s Wheeling Suspension Bridge over the Ohio River with a span of 308 meters, opened in 1849. The German immigrant John August Roebling founded his own steel wire mill, constructed a number of suspension bridges and finally built New York's Brooklyn Bridge opened in 1883 with the world record span of its time of 486 meters. In 2017 this iconic bridge was nominated on the WH Tentative List of the USA.

In the 20th century, a large number of giant suspension bridges were built. The best known is Golden Gate Bridge in San Francisco, opened 1937 with the record span of 1280 meters. Most of these bridges did not rely anymore on the mixture of systems but were purely of the suspension type.

The cable-stay system, a development from the cantilevered bridge using pylons and wire cables to suspend the deck structure, is today often used to construct large span bridges. Although not yet old enough to become a World Heritage Site, the Millau Viaduct in central France, designed by Sir Norman Foster with a total length of 2460 meters and pylon height of 343 meters, might be qualifying as the most spectacular bridge of this type.

fig. 9: The Millau viaduct in central France, a future World Heritage Site? (© Rolf Höhmann)

5. Moveable Bridges and Transporter Bridges

The special category of bridges, that either move or have moving parts is relatively small, but at least one is already a WH site.

Bridges which can either swing, be lifted, floating or rolled away to give space for larger or higher ships, are spread around the world. Eric DeLony gives some examples like the well-known Tower (lifting) Bridge in London and three very different US bridges: Fort Madison double-deck swing bridge completed in 1927, the 1940 Lacey W. Murrow Memorial (floating) bridge at Lake Washington and the Sault-Sainte-Marie International Railroad Bridge in Michigan, a unique combination of Warren trusses, a bascule (flapping) bridge and a newer lifting bridge from 1959. While older examples exist, a deeper survey of these bridge types seems to be necessary for further evaluations, including newer giant swing bridges at the Suez Canal and others.

In contrast, Transporter Bridges are fully documented. Only 8 out of a total of 22 worldwide survive. The 2006 World Heritage listing of the first transporter bridge built, Puente Vizcaya in Bilbao in Spain, initiated the collaboration between the remaining 7 transporter bridges in Argentina, France, Germany and the United Kingdom to develop a serial nomination, which did not succeed yet. They were all built in the relatively short timeframe between 1900 and 1916.

The Vizcaya Bridge was a joint project of the Basque inventor Andrea de Palacio and the French engineer Ferdinand Arnodin, who introduced his knowledge of suspension and cable-stayed bridge construction for this first bridge from 1893, which was patented for both men. Arnodin built several other transporter bridges to the same design, notably also one in Newport/Wales in 1906. The principle of this bridge type is running a ferry suspended from a high-level girder or truss, which allows the passage of high ocean-going ships and sailboats. The girders in the different examples show all types discussed already: Suspension and cable-stayed, cantilevered, rigid truss e.a.

fig. 10: Puente da Vizcaya was the first Transporter Bridge built and became a World Heritage Site in 2006 (© Rolf Höhmann)

5. Conclusion

Stone arch bridges are very well represented in the World Heritage List, Tentative List proposals from Turkey and Iran could widen the geographical spread. Steel arches from the 19th century are not yet present in the list, as are steel girders and truss bridges. The innovative types in the USA and the tube and lattice girders of Conwy and Dirschau should be discussed for this. The Dirschau bridge has a special value in being partly destroyed in Second World War and is now preserved in a joint polish-german effort. The Malleco Viaduct could give a geographical enlargement into South America. The cantilever system is well represented by the Forth Bridge, while the Viaduc du Viaur, which is also a three-hinged arch may be integrated into the arch-category.

Suspension bridges are not yet listed, but two bridges of the mixed suspension/cable-stayed kind are on Tentative List proposals: Brooklyn Bridge and Puente des Occidente in Columbia, a rare example of a WH technical monument in South America. The chain-type could be represented by Telford´s Conwy Suspension Bridge. Together with the neighbouring Stephenson´s tubular bridge and Conwy castle, this could become a very interesting WH site, although there are some problems with the authenticity. An outstanding moveable bridge qualified to become a World Heritage has not been found yet. The transporter bridges are well represented with the pioneer structure in Bilbao but might all become World Heritage sites - the first time that a complete technical building type with all survivors is fully preserved.

CHAPTER 3:

POTENTIAL SERIAL WORLD HERITAGE PROPERTIES

MARIA PIA AND LUIZ I; TWO IRON ARCH BRIDGES OVER THE RIVER DOURO

Antonio Adao da Fonseca

The River Douro springs on the East side of the Iberian Peninsula and goes all the way to the West, in search of its destiny, the Atlantic Ocean. On its way, its nurtures three of the most successful wine Regions: “Rioja”, “Ribera del Duero” and “Douro” (Figure 1), the latter being the cradle of the supreme wine: The Port Wine. After meandering along the Iberian Plateau and immediately after the “Ribera del Duero” Region, the river carves deep canyons dividing Portugal from Spain, before running West across Portugal through hills with steep slopes where the Douro and Port grapes grow. Just before reaching the Ocean, along the 5 km stretch where the river separates the two cities facing each other (Porto, on the north side, and Gaia, in the south side), high margins contain the River Douro in a riverbed around 200 meters wide.

fig.1: Three wine regions nurtured by the River Douro (© Google Earth 2017 with notes by Adao da Fonseca)

When heavy and persistent rains fall in the Cantabrian Mountains and in the North of Portugal, colossal quantities of water go down the Douro River. Then, water speeds up between the two cities to the point that “flying” bridges over the waters have been the logical design option, with no supports inside the riverbed.

For Centuries, before iron came to be also a structural material, only temporary bridges of boats were installed to cross the River, preferably in dry months. Of bad memory is the one that collapsed in 1806 under the population fleeing south from the approaching Napoleonic Army, on 29 March 1809.

Soon iron as a structural material developed, and a pedestrian suspension bridge was built in 1841 between two small rock headlands and high enough to guarantee no river flood could reach it. Moreover, industrialization came and the second half of the 19th Century sees the construction of the railway line from Lisbon, the Portuguese Capital, to the more populous Northern Portugal and to its leading city: Porto. For this, a huge challenge had to be overcome: passing the train over the Douro River at high level.

In the presence of rocky banks and the need to pass trains at a height of about 60 meters, the structural solution of deck supported in an arch is undoubtedly an excellent, if not the best, option. The railway iron Maria Pia Bridge was the first arch bridge over the River Douro, located at the very beginning of that 5 km stretch of the River Douro, between the cities of Gaia and Porto (Figure 2).

fig. 2: Four arch bridges between Porto and Gaia (© Google Earth 2017 with notes by Adao da Fonseca)

Still in the 19th Century, the iron Luiz I Bridge was built with two decks and next to the pedestrian suspension bridge. The low-level deck took the traffic from the suspension bridge, which was soon demolished, and the high-level deck provided the connection between the uplands above. More than 70 years passed until the motorway Arrabida Bridge came to be constructed, in reinforced concrete. It was already in the 21st Century that the Infant Dom Henrique Bridge came to “be”, with a very “delicate” reinforced concrete arch supporting a “powerful” prestressed concrete deck for road traffic.

Then, let us study very briefly the structural functioning of arch bridges, for which Figure 3 should be observed attentively.

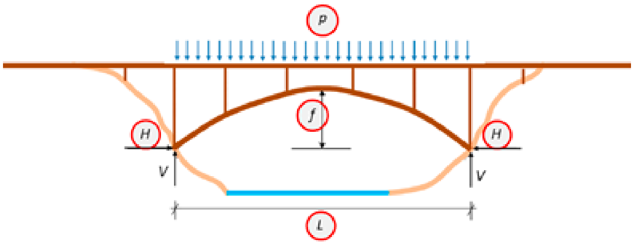

fig. 3: Arch bridge geometric parameters

where

- *L* is the span of the arch
- *f* is the rise of the arch
- *p* is the distributed load per meter of deck length (including weights of deck, arch and columns, and weights of rolling loads upon the bridge)
- *H* is the horizontal component of the ground reaction, also named "arch thrust"
- *V* is the vertical component of the ground reaction

Value of load p and thus the value of vertical reactions V depend very much on deck width and on spans between columns, but not so much on arch span L. Then, for a given span L, the fundamental geometric parameter is rise f.

To explain the implications of distinct values of those parameters L and f, consider the example of a river crossed by an arch bridge with the following alternative geometries for the arch (Figure 4):

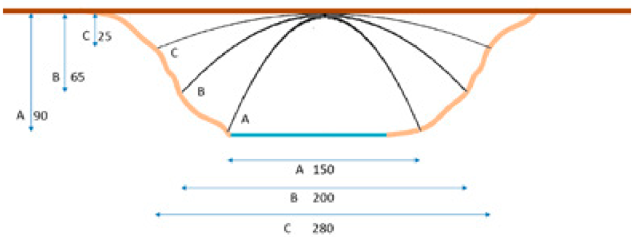

fig. 4: Example of the arch bridge with 3 alternative geometric parameters L and f

Ratio L/f is the shallowness of the arch, and it can be said that measures also the "difficulty" of the construction of the arch bridge. Most important, those parameters govern the value of the arch thrust H, according to the following formula:

Values for the 3 alternatives are presented in the following table:

OPTION	arch span *L* (m)	arch rise *f* (m)	shallowness *L/f*	*H*
A	150	90	1.67	31 *p*
B	200	65	3.08	77 *p*
C	280	25	11.2	392 *p*

It should be noted variation of both shallowness and arch thrust H. When the span L increases by 1.87, shallowness increases 6.71 and arch thrust H increases 12.6.

That table applied to the four Douro arch bridges becomes as follows:

BRIDGE	arch span *L* (m)	arch rise *f* (m)	shallowness *L/f*	*H* (loading p is not the same for all bridges)
Maria Pia	167	43	3.9	81 p1
Luiz I	172	45	3.9	82 p2
Arrabida	270	52	5.2	175 p3
Infant Dom Henrique	280	25	11.2	392 p4

All these bridges are outstanding (Figure 5).

fig. 5: Four World Record Arch Bridges over River Douro, between Porto and Gaia (© Arte Fotografica)

It is noteworthy that the value of the arch thrust H on the Infant Dom Henrique Bridge is the highest in the world, far surpassing the values of newly constructed concrete arch bridges in China, with spans greater than 450 meters.

The architecture and engineering of the two concrete bridges are extraordinary, but the relevance of the two iron bridges built in the 19th Century gives them a very special place in the History of Bridges. They were built at a time when the iron was still evolving into steel, when construction equipment was yet very basic, and when cantilever construction was giving the first steps.

Both the Maria Pia Bridge and Luis I Bridge arches, columns and decks are trusses built by the cantilever method, meaning that those trusses (Figures 6 to 9) grew as cantilevers over the river.

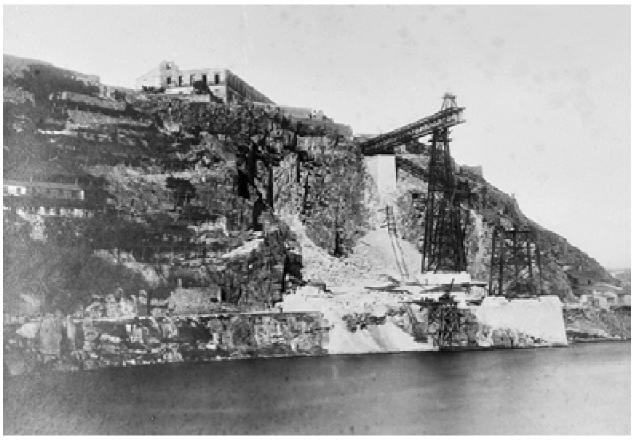

fig. 6: MARIA PIA BRIDGE - Column and deck on the right margin, advancing as cantilevers by 19th Century photographs of unknown authors

Since no equipment for heavy lifting was available, individual bars or small pieces of truss were transported to their location of continuity.

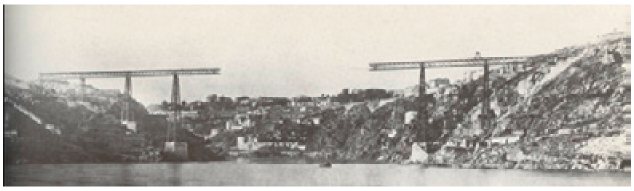

fig.7: MARIA PIA BRIDGE - Abutments ready for arch construction to start by 19th Century photographs of unknown authors

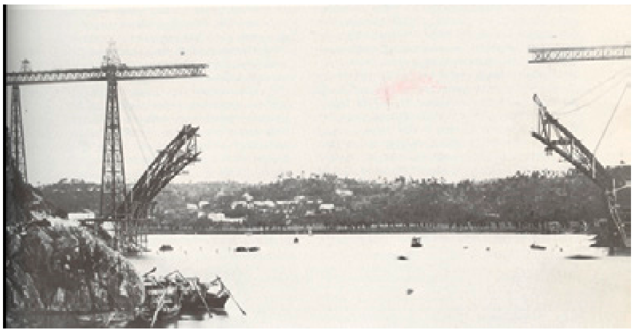

fig.8: MARIA PIA BRIDGE – Arch construction with stays from top of columns by 19th Century photographs of unknown authors

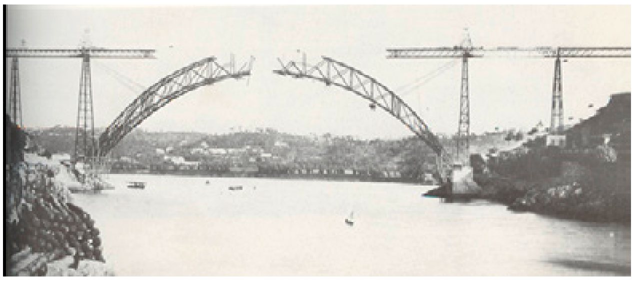

fig. 9: MARIA PIA BRIDGE – Arch almost closed at the top by 19th Century photographs of unknown authors

Figure 10 shows the bridge in service, still with a steam engine passing.

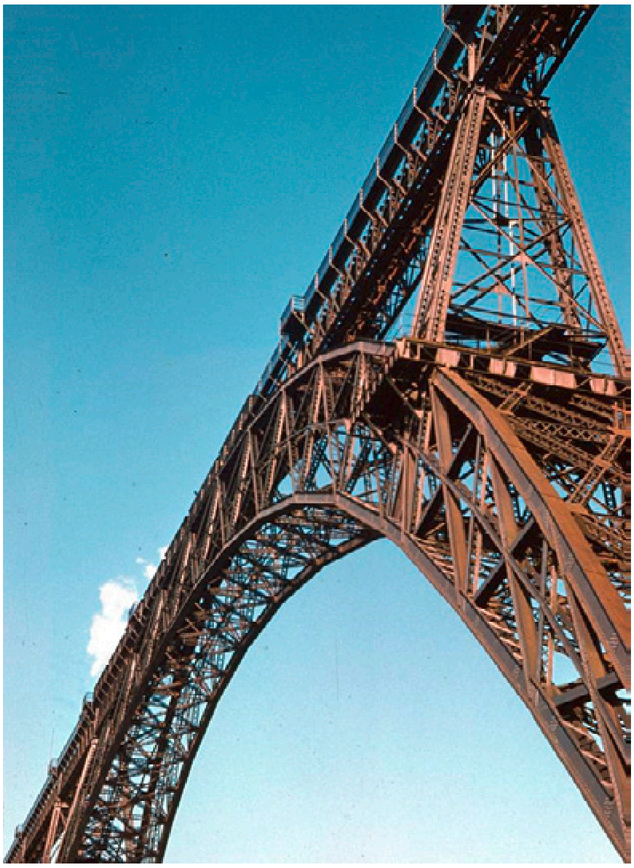

fig.10: MARIA PIA BRIDGE with steam engine passing (photograph was taken in 1959) (© Aureliano da Fonseca)

The deck had only one rail track, which was a great shortcoming for the increasing traffic. More important, the bridge was not very stiff sideways and trains had to cross it in slow motion. Railway catenary (Figure 11) was installed in the bridge in 1966, but no heavy trains or engines could use it.

fig. 11: MARIA PIA BRIDGE already with electrical catenary (photograph was taken in 1968) (© Aureliano da Fonseca)

Therefore, pressure for the replacement of the bridge was growing very strongly, but the right decision was taken to conserve it and a new railway bridge was built 150 meters upstream.

The MARIA PIA BRIDGE is a masterpiece produced by the genius of the entrepreneur Alexandre Gustave Eiffel and by the superb structural design capacities of his partner François Gustave Théophile Seyrig. The bridge has been waiting for a new use since 1991, and the struggle to find a new purpose is a major concern for us all.

Contrary to nowadays, in the 19th Century railways were given priority over roads. However, motorized traffic was coming strong, and just a few years after the Maria Pia was inaugurated, another international competition was launched for the construction of a double-deck bridge serving both traffic along the riverbanks and traffic in the plateaux above. In the meantime, Théophile Seyrig separated from Gustave Eiffel and the former joined the Belgian enterprise Société de Willebroek. Twelve solutions were presented, and the contract for the construction of the LUIZ I BRIDGE was awarded to the Société de Willebroek in November 1981.

No wonder, the design of this bridge resembled that of the Maria Pia Bridge since the structural designer is the same. Indeed Figures 12 and 13 recall Figures 8 and 9 above.

fig. 12: LUIZ I BRIDGE – arch initiating construction by 19th Century photographs of unknown authors

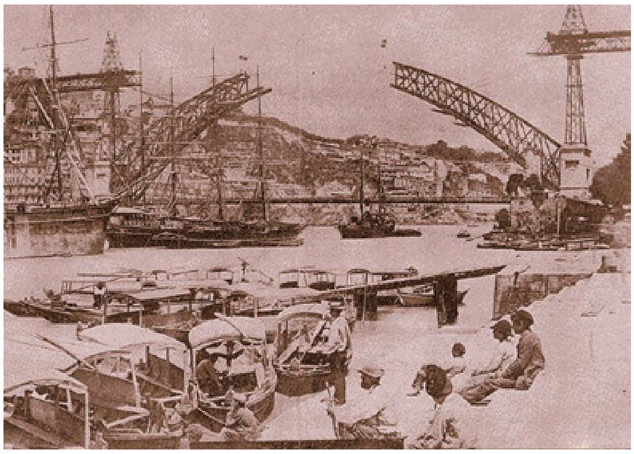

fig. 13: LUIZ I BRIDGE – arch under construction, with the suspension bridge in front by 19th Century photographs of unknown authors

The bridge was opened to traffic in 1889 and gave a big push to the economic activity in the region (Figure 14).

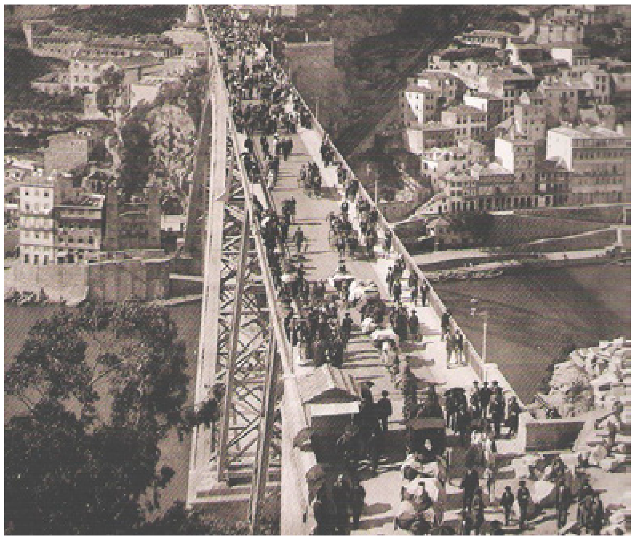

fig. 14: LUIZ I BRIDGE – crowded upper deck by 19th Century photographs of unknown authors

The suspension bridge did not live long after the Luis I Bridge enter service (Figure 15).

fig. 15: LUIZ I BRIDGE side by side with the suspension pedestrian bridge (© Aureliano da Fonseca)

fig. 16: LUIZ I BRIDGE in a misty winter day (photograph taken in 1956) (© Aureliano da Fonseca)

The Luiz I Bridge became the ex-libris of the joint cities of Porto and Gaia. Its location very much in the middle of the old towns is magical (Figure 16).

For this bridge, there is no shortage of ideas for new uses. In 2003, road traffic was moved from the upper deck to the new Infant Dom Henrique Bridge to allow Light Metro to cross the River Douro, and a ideas for the use of the lower deck are advanced every day.

EIFFEL TWIN BRIDGES: MARIA PIA AND GARABIT VIADUCTS

Bertrand Lemoine

Two major arch bridges stand out as essential contributions in the field of large iron bridges: Maria Pia Bridge in Porto and Garabit Bridge in France, both constructed by the same builder, Gustave Eiffel.

Born in 1832, Eiffel graduated from the prestigious Ecole Centrale des Arts et Manufactures in 1855. He began his career by supervising in 1857-1860 the construction of Bordeaux railway bridge, the longest iron trussed bridge of its type in France at the time (504 m), now listed in UNESCO WHL.

Eiffel founded his own construction company in 1864, aged 32, under the brand name « Gustave Eiffel Constructeur ». His first large commission was in 1867 the building of an iron railway viaduct over the Sioule river in central France, as well as a similar smaller one on the same railway line. Designed by Wilhem Nordling, it shows the main girder pushed into place, with a maximum span of 58 metres. The deck is supported by curved tubular cast iron piles built from above.

Eiffel associated in 1868 with Theophile Seyrig, an engineer, ten years younger than him, graduated major of the Ecole Centrale in 1865. Seyrig not only brought in his expertise but also invested money in the « Gustave Eiffel and Cie » company, although Eiffel remained the only Director. This helped Eiffel get two major commissions in 1875: the Pest railway station in Hungary and the Maria Pia railway bridge in Portugal.

An international competition was launched in 1875 by the Royal Company of Portuguese Railways for a 400 metres valley crossing, including 150 meters to cross the Douro river in Porto, to avoid 12 kilometres of ramps and detour. Four tenders were submitted, one by a British company and three by French companies: Fives-Lille, Gouin, and Eiffel.

As head of the design and calculation department of Eiffel company, Seyrig proposed a very innovative 160 metres single span arch. The total estimated cost was 1.35 million francs, ie. 2900 francs/linear metre against 8900 francs/ linear metre for the most costly project because no scaffolding was needed to build Seyrig's design. The contract was signed in June 1875.

fig. 1: General view of Maria Pia Viaduct (© B. Lemoine)
Base of Maria Pia Viaduct (© B. Lemoine)

The Maria Pia Bridge presents a circular arch, wider at the base, with hinges at the bottom of the arch, facilitating both the calculations and erection. The total length of the bridge is 353 m long and it raises 61 metres above the water. It used 1450 tons of iron fabricated in Eiffel workshop, located in Levallois-Perret near Paris. Émile Nouguier and Jean Compagnon were hired (from Gouin) to supervise the works on site. The bridge was completed on time in November 1877. A model of the bridge was presented at the World Exhibition in Paris in 1878. It has been closed to railway traffic in 1991 and has remained unused.

The Garabit Bridge was also built by Eiffel Company just a few years later. It is very similar to Maria Pia bridge and can be considered as its twin, although there are some minor differences between both bridges. The Garabit Bridge is part of the Neussargues to Marvejols railway line (on the Paris to Beziers line) in the Massif Central, to allow for better communication from Paris to the south of France, initiated by the French State. Léon Boyer, young resident State engineer aged 27 and in charge of this line since 1878 proposed in December of the same year to build a bridge for crossing the Truyère valley, instead of a long detour, saving 3 million francs. He designed a project directly inspired by the Maria Pia bridge. Eiffel was thus directly commissioned by the State on June 14, 1879, to build the whole bridge, with no bidding, at a cost of 3.39 million francs. This was a great success for the Company, with a much higher income than Maria Pia Bridge, despite harsh local conditions and a greater length.

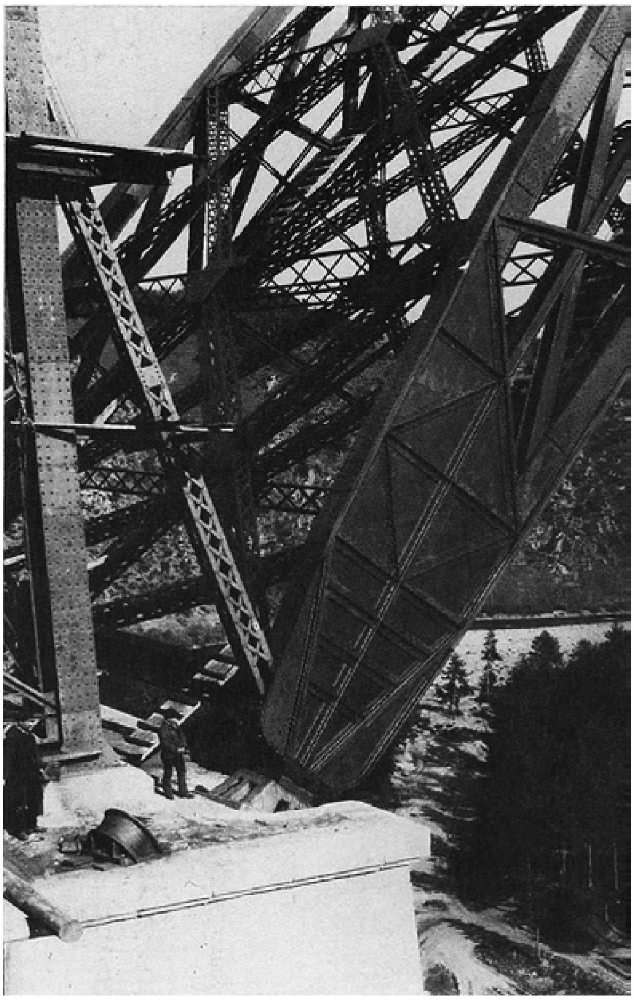

fig. 2: General view of Garabit Viaduct (© B. Lemoine), Base of Garabit Viduct, 1884.

Seyrig wanted his share of the profit but Eiffel refused and on June 30, 1879, broke the contract with Seyrig, who left the company to join a Belgian construction firm (Company of Willebroeck). Maurice Koechlin who just graduated from Zurich Polytechnicum under Karl Culmann was appointed by Eiffel on October 19, 1879, to do the Garabit calculations (using 7 digits logarithms tables), which were also verified by Boyer. The total length of the bridge was 564,69 metres, with a central span of 165 metres, quite similar to Maria Pia. The total height was 122 metres, with piles up to 60.74 metres. The weight of the bridge is 3 169 tons of iron (1200 for the arch) including 678 768 rivets.

The first step of the construction was to build a village, with accommodation for 400 workers and even a school. Like in Maria Pia, no scaffolding was needed to build the arch. A temporary wood bridge 33 metres high was built to bring right at the foot of the bridge the prepainted prefabricated iron elements coming from the Levallois-Perret factory, ready to be assembled by rivets. Horses and oxen were used to bring the material on site, with the help of small steam engine cranes on the deck.

Preliminary works began in September 1880, followed on August 1882 by the construction of the masonry piles. The construction of the arch was initiated simultaneously on both sides on June 24, 1883, and the junction between the two halves of the arch took place on April 26, 1884, only ten months later. The deck itself was built on the banks, on both sides. It was then slid into place at the speed of 8,25 metres/day. The bridge was opened to traffic on November 10, 1888. In the meantime, Boyer had moved to Panama in December 1885 to manage the Canal project but died there in May 1886 from yellow fever.

The site of Garabit viaduct has been modified since its erection. The construction of the Grandval dam has resulted in the creation of a large lake which diminishes the apparent height of the bridge but which gives a potential reflection of the image of the bridge on the water below. The colour of the bridge has also been changed, into a deep red.

Maria Pia and Garabit are similar in overall design but there are some differences. The first one has a span of 160 metres versus 165 metres, a circular arch versus a parabolic arch, the position of the deck is different as well as the small piles. The rails are positioned above the main girder versus inside the main girder for better wind protection. The bracing of the piles is also different, with either closed or opened box girders.

Eventually, Seyrig was also responsible in 1886 with the Willebroeck Company for the building of another exceptional bridge in Porto, the Luiz I Bridge. It is also an arch bridge similar in design and span to Maria Pia but the base hinges incorporated in the widening of the arch. It has two decks, with a suspended lower deck. Both decks carry road traffic but an urban metro has been set on the top deck during the restoration of the bridge in 2005.

Both Maria Pia and Garabit bridges are magnificent works that opened the way to further bridge design improvement. The elegance of the arch curve matches with the feeling of strength and balance expressed by the bridge. Clearly, both technical achievements opened the way to the conception and construction of Eiffel's masterpiece, the Eiffel tower, with the same concepts and technical staff involved.

THE SAN MICHELE BRIDGE (1889): HISTORIC BACKGROUND, RECENT ASSESSMENT, AND MONITORING, FUTURE PROSPECTS

Antonella Saisi and Carmelo Gentile

Abstract

The San Michele bridge is an iron arch bridge that crosses the Adda river about 50 km far from Milan. The bridge, built in 1889, is the most important monument of XIX century iron architecture in Italy and is still used as a combined road and railway bridge. In order to assess the structural condition of the bridge, ambient vibration tests were performed in 2009 and suggested the opportunity of installing a permanent dynamic monitoring system with Structural Health Monitoring purpose. Hence, a continuous monitoring system was designed and installed on the bridge from 28/11/2011 to 24/04/2015. The paper, after a brief summary of the experimental studies developed since 2009, describes the monitoring system and the software developed in LabVIEW for processing the collected data. Subsequently, the tracking of natural frequencies automatically identified until the beginning of September 2012 is presented and the effects of environmental and operational conditions on the dynamic response of the bridge are investigated.

Keywords: Arch Bridge; Iron Structure; Industrial Archeology; Diagnosis of Historic Structures; Dynamic Testing; Continuous Dynamic Monitoring; FE; Heritage; Preservation Strategy.

1. Introduction

The San Michele bridge (Fig. 1), better known as Paderno bridge, is an iron arch bridge that was built between 1887 and 1889 by the Società Nazionale delle Officine di Savigliano (SNOS) to complete one of the first Italian railway lines (the link between Ponte S. Pietro and Seregno) and to comply with the needs of the rapidly growing industrial activities in the Lombardia region at the end of XIX century (SNOS, 1889), (Politecnico, 1889), (Nascè et al., 1984).

The historic infrastructure, protected by the Italian Ministry of Cultural Heritage since 1980, is a symbol of the industrial archaeology heritage in Italy and shares its structural architecture with similar iron arch bridges built in Europe at the time, such as the Garabit viaduct in France (built by Eiffel and Boyer in 1884), the Maria Pia bridge (built by Eiffel and Seyrig 1877) and the Luiz I bridge (built by Seyrig 1885) in Porto.

The main structural elements of the bridge are a parabolic iron arch, with a span of 150 m, and a truss-box metal girder, 266 m long, resting on nine equally spaced bearings.

The railway bridges, built between the second half of 19th century and the beginning of 20th century, have historic significance – embodying the distinctive characteristics of the construction methods of the time, mainly related to masonry and iron structures - and often represent a distinguishable but harmonized entity in landscapes. The railway bridges are, at the same time, architectonic heritage and frequently innovative structures, solving problems of environmental impact with bold engineering solutions related to the requirements of the railways loads, so that the structural dimensions of piers and spans stem from the optimization of the planned railway routes. In addition, these structures were the top of the technology, engineering, and architecture of the time, showing a deep knowledge of materials and technological solutions no more in use; due to the high quality of design, these bridges have often shown a remarkable lifetime and are, in many cases, still in service. Historical railway bridges own to two different cultural ambits, often conflicting between them: on one hand they are meaningful cultural heritage often merged to impressive natural/built landscapes; on the other hand, they are infrastructures which should guarantying standards and code requirement for new structures, when still in use. Recognizing historical and documentary values of the heritage, the approach to the structure conservation should fit restoration issues as recommended in several national and international documents as Recommendations for the Analysis and Restoration of Architectural Heritage (ICOMOS/ ISCARSAH, 2005). The interventions have to guarantee principles as the respect of the structural authenticity, the compatibility of the use with the structure characteristics, a minimal intervention non-invasive, the monitorability.

Codes and prescriptions related to the infrastructure do not take into account differentiated safety requirement for existing and new structures; further critical issues are the continuing increasing requirement, in terms of either number of daily passages or increase of weight and speed of the trains, and the lack of addressed investigation and analytical procedure aimed at the control of such important structures.

Once the infrastructure is considered obsolete, the general practice is the replacement with a new one. This was the case of the iron bridge at Trezzo d'Adda (Röthlisberger, 1886 a,b), built by Società Officine di Savigliano between 1884 and 1886 and demolished in 1946. Despite it was considered unsafe, it was used to support the new bridge during the construction.

An alternative to the replacement is the downgrading the use of the bridge to cycle or pedestrian use. The solution could be risky for the structure, not guarantying the systematic maintenance necessary for metallic carpentry generally expected for the continue railway use. In short time, the state of the structure would worse up to the closing or the demolishing. This was the case of the Roncigli-one bridge in Italy, an interesting railway arch bridge dated back to 1928, or of the Saint-Jean footbridge in Bordeaux saved after a strong action by UNESCO and by the French Heritage authorities. Nevertheless, collecting funds from the several CH administrations could be a challenging task, taking into account the wide competition.

A more reliable alternative would suggest to the keep the present use of the bridge, within precise strategies. It requires addressed plans – cultural and technical – for the conservation and/or repair of the structure through the evaluation of the current conditions of the materials and of the structure, the potential vulnerability, and the actual re-use possibility. The processing of the collected information leads to conservation projects and re-use programs having as priority the safety of the structure, the compatibility with the structure characteristic, the respect of the pre-existence, the respect of the historical, cultural, documentary values according to the Restoration Principles and Recommendations for the Analysis and Restoration of Architectural Heritage (ICOMOS/ ISCARSAH, 2005). Within this approach, the diagnosis and the monitoring of the structure are key factors for the addressing of the following strategies.

The evaluation seems especially complex for historic iron bridges, in absence of systematic research on the technological and mechanical properties of the material and on its durability. Further uncertainties concern the behavior of the assemblages and jointing, which often drive the crisis of the system. The diagnosis should result from the experimental investigation, both on-site and in the laboratory, and from the structural analysis, based on appropriate mathematical models. The experimental phase is aimed to define the material properties, construction details, internal composition, general characteristics of the structure itself and localize eventual defects. The investigation on the iron member is generally addressed to the local material evaluation and corrosion inspection, collecting parameters not easily linkable to the whole structure behavior. The analytical model of a historic structure, even when based on the original drawings, accurate field survey and mechanic characterization of the materials, always involves simplifying assumptions and several uncertainties in the material and geometric properties and boundary conditions; hence, the model possibly needs to be validated by full-scale tests. Within this context, operation modal analysis could have a key-role, involving the global behavior of the structure and providing meaningful parameters for the model calibration. A further advantage, in case of strategic infrastructures like railway bridges, is the possibility to keep in use the structure during the investigation campaigns. The availability of an effective model, representative of the real structure in its present state of preservation is the starting point of any assessment evaluation. For this reason, a wide experimental campaign should mandatory precede the analytic phase of the structural assessment of such historic infrastructures. Furthermore, the international debate concerning the assessment of historic structures and the possible following interventions, define a series of requirements or criteria oriented to ascertain the efficiency of the solution together with its compliance with recognized conservation principles. Between the several requirements, it is worth to mention the priority of the structure monitoring, even long-term, in order to check the stability in a time of the building behavior.

Notwithstanding the lack of maintenance and the poor state of preservation of the structure, significantly damaged by corrosion, the San Michele bridge is still used as a combined road and rail bridge, with the top deck of the truss-box girder carrying one lane of alternate road traffic and the bottom deck housing the tracks of a single-line railway (Figures 1-2). Although the weight and speed of vehicles are limited (180 kN/axis and 15 km/h for the trains, 35 kN and 20 km/h for the road vehicles), the bridge has not been saved from the progressive increase in road and rail traffic, generally experienced by the infrastructures during the past years. For example, the daily train passages (at present 53) were triplicate from the ,80s and the one-way road traffic loads the bridge almost continuously during the day.

According to the restoration practice, the authors carried out the research by collecting information concerning the structure evolution, the evaluation of the state of preservation and of the overall structural condition by Structural Health Monitoring (SHM) program of the bridge, addressed by a series of preliminary dynamic tests in operational conditions between June 2009 and March 2010 (Gentile and Saisi, 2011).

After a brief description of the historic bridge, the paper summarizes the main results obtained from the application of different output-only modal identification techniques to the data collected in the dynamic tests. It is worth underlining that the above dynamic tests represented the first global experimental survey performed on the bridge since the load reception tests (1889 and 1892) and the identified dynamic characteristics clearly highlighted the opportunity of installing a permanent dynamic monitoring system with SHM purposes. The research program was complemented by the development of a linear FE model, accurately representing the geometry of the bridge in its present condition; the model included all the available information provided by the original design drawings as well as by the drawings and documents illustrating the main retrofit interventions carried out over the time.

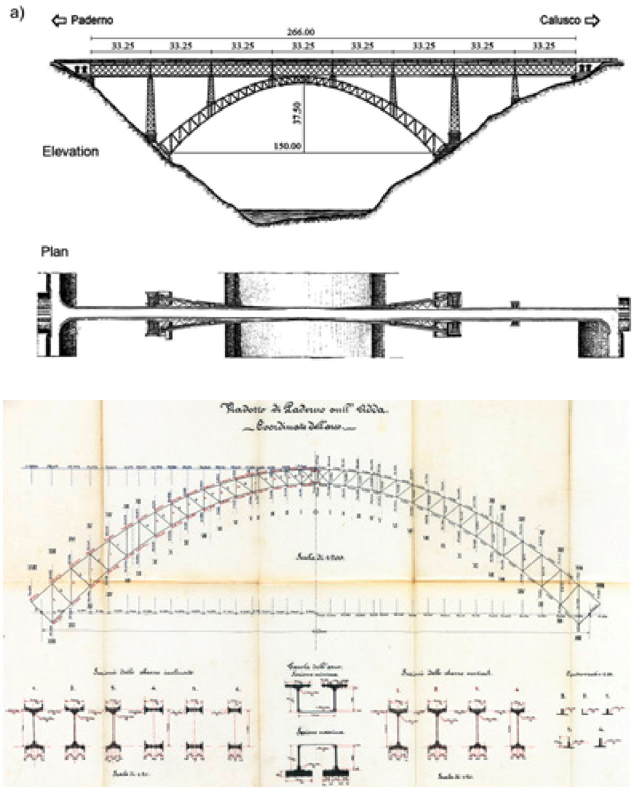

Fig. 2. a) Elevation and plan of the Paderno bridge (modified from (Politecnico 1889) (dimensions in m); b) arch coordinates and cross-sections of the members (modified scan from State Archive of Turin)

fig.1: Views of the Paderno iron arch bridge (1889) (© Saisi and Gentile)

2. Historical Background and Description of the Bridge

The Paderno bridge was designed in 1886 by the head of SNOS technical division, the Swiss engineer Julius (or Giulio) Röthlisberger (1851–1911), through the rigorous application of the Theory of the Ellipse of Elasticity (Culman, 1866). SNOS, a company from Turin, was involved in the building of the main Italian infrastructures and buildings in iron and steel carpentry from the second half of XIX century. Julius Röthlisberger studied in Zurich (1868-1872) with Karl Culmann, developing a deep knowledge about graphical statics of engineering structures (Röthlisberger, 1886 a,b), (SNOS, 1889). Highly formative was the period passed in Bern working at Gottlieb Ott & Cie. (1872 -1882) with Moritz Probst and Paul Simons. At Gottlieb Ott & Cie. Röthlisberger was involved in the buildings of important iron arch bridges like Kirchenfeldbruecke in Bern (1881-83) and the Schwarzwasser Bridge (1881-82) designed in collaboration with P.Simons (Röthlisberger and Simons, 1884). With P. Simons, Röthlisberger opened in 1883 offices in Bern and Milan, applying to international competitions of bridge buildings. They were awarded for the high quality of the technical drawings, appreciable in the drawings of the San Michele Bridge, as well. Since 1885, Röthlisberger worked at SNOS in Turin, starting a fruitful collaboration as technical director starting with the bridge of Trezzo d'Adda (Röthlisberger, 1886 a,b).

After a preliminary proposal, a national competition of the Italian Government was opened for the design of the bridge in Paderno, the last stretch of an important railway line because of the challenging crossing of the Adda river. Despite the diffused opinion against metallic carpentry considered low durable and with high maintenance costs, Rothlisberger's design was preferred to other entries into a competition held by the Italian government due to the lower costs, three years of maintenance and to the scheduled erection time of only 18 months: the construction officially began on September 1887 and was completed on March 1889 (Politecnico, 1889). The drawings, kept in the State Archive of Turin (Nascè et al., 1984), (Bertolini, 1989), are very detailed, including specific drawings for the inspection ways and the scaffolding structure that were accurately designed to guarantee the control and the maintenance and to prevent incident to the workers, as well.

The bridge consists of a parabolic arch, a truss-box girder and a series of piers (Figures 1-2). Three piers are erected from masonry basements while the others are supported by the arch; all the piers are battered in both directions, according to the European practice of the late XIX century.

The arch consists of two ribs, with a span of about 150.0 m and a rise of 37.5 m; each rib is composed of double members (1.0 m apart) and has a variable height, of 8.0 m near the supports and 4.0 m at the crown. Since the two parabolic arch ribs are canted inward, their distance is variable between 5.0 m at the crown and about 16.35 m at the basements.

The deck is 266.0 m long and consists of 8 equal spans. The deck vertical trusses, 6.25 m high and 5.0 m apart, support two roadways: the upper one for road and pedestrian traffic, and the lower for a single line of railroad. All the iron members of the bridge have T or C shaped composite section and are formed by riveted flats and angles (Fig. 2b).

According to the international classification of Philadelphia (1876), the bridge material can be classified as „wrought iron". Tests carried out on few samples of the bridge members between 1955 and 1972 (Nascè et al., 1984) revealed rather poor metallurgical, chemical and mechanical characteristics. The material is characterized by a stratified structure along the rolling plane and frequent non-metallic inclusions; the yield strength is generally larger than 240 MPa, with a tensile strength often less than 300 MPa and rather low (4-12%) elongation. The bridge – opened on May 20, 1889 – underwent major modifications and repairs during its history (Nascè et al., 1984); in particular: (a) between 1953 and 1956, the damages caused by the II World War were repaired and the entire structure was re-painted; (b) in 1972, the roadway deck (originally with Zorès beams) was replaced by a steel orthotropic deck; (c) in the early '90s, maintenance and repair of the truss-box girder involved replacement of damaged members, stiffening of the girder, sand-blasting and painting of the structural elements (Nascè, 1993).

Due to the historic importance of the bridge, almost all the original drawings are available in the State Archives of Turin whereas the repair interventions are well documented in the archives of the Italian Railway Authority (RFI). In addition, a valuable and comprehensive study of the bridge history and structural characteristics is reported in (SNOS, 1889), (Poltecnico, 1889), (Nascè et al., 1984), (Bertolini, 1989).

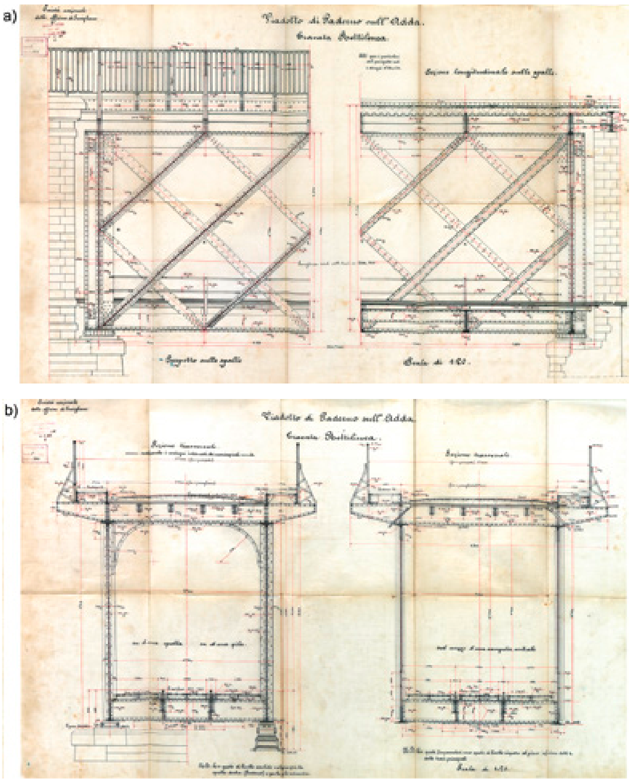

fig.3: a) Front and longitudinal section of the girder of the Paderno bridge; b) cross-sections (modified scans from State Archive of Turin)

3. On-Site Survey

The state of preservation of the bridge is rather poor due to the lack of maintenance. The bridge was re-painted in 1956 during repair in intervention after WW2 and limited to the truss-box girder in 1990.

According to the designed lifecycle and the program of the Italian Railway Authority, the bridge was going to be turn down after 100 years of service that was 1990. However, a strong action of the Italian Ministry of Cultural Heritage prevented the planned demolition, listing the bridge between the national heritage since 1980. The inspection carried out by the authors was limited to the truss beam, because the inspection ways, accurately designed by Röthlisberger, were not practicable. Recently, RFI has completed the arch and piers inspections by the collaboration of climbers.

The state of conservation shows signs of decay and local corrosion that reflect all the problems and uncertainties of intervention on these structures; Fig. 4 exemplifies typical damages induced by the corrosion, observed on a huge number of structural members. It should be noticed that the large spacing of the rivets, not adequate to the thickness of the iron plates, easily allows the penetration of moisture between the contact planes so that the subsequent oxide expansion induces deformations of the iron plates and sections at the connections of the composite struts.

The on-site activities were systematically planned in order to detect and classify the damage of each structural member (Fig. 5a), according to the practice in restoration. The damage of each beam is classified and the details recorded in forms (Fig. 5b). The visual inspections are supplemented with measurement of the deformation due to the corrosion (Fig. 6).

fig.4: Examples of members damaged by the corrosion (© Saisi and Gentile)

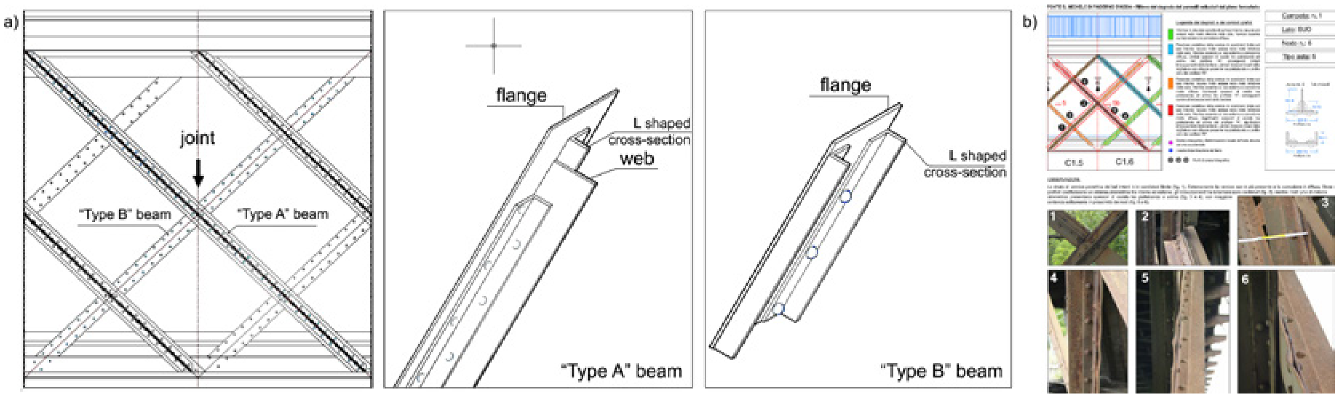

fig.5: Scheme of the surveyed beam types a) and b) example of survey form (in Italian) (© Saisi and Gentile)

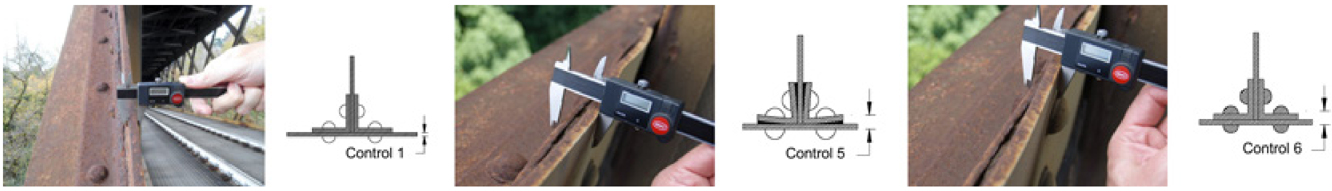

fig.6: Details of the controls of the iron members (© Saisi and Gentile)

4. Ambient Vibration Tests

Several ambient vibration tests (AVTs) were carried out by the VibLab (Laboratory of Vibrations and Dynamic Monitoring of Structures) of Politecnico di Milano on the Paderno bridge between June 2009 and June 2011, in order to characterize the dynamic behavior of the structure and for addressing a SHM program (Gentile and Saisi, 2011). Three AVTs were firstly carried out between June and October 2009 on the roadway deck of the bridge instrumenting 17 sections, while the following tests were extended to the railway-deck bridge instrumenting 7 cross-sections as well; each cross-section was equipped with 3 sensors, in order to measure the vertical accelerations, on the downstream and upstream sides, and the lateral acceleration. It is worth underlining that those tests represented the first experimental survey carried out on the global characteristics of the bridge since the original static proof tests (1889-1892) (SNOS, 1889), (Nascè et al., 1984), (Bertolini, 1989). The first test, (June 2009) was aimed at investigating the vertical dynamic behavior of the bridge; the subsequent two tests were performed to check the possible variation over time of the previously identified resonant frequencies (September 2009) and to investigate the transverse dynamic behavior (October 2009), respectively. In the last tests the response was continuously recorded at the points scheduled for permanent monitoring for 15 and 24 hours, respectively. The tests were mainly aimed at the checking the possible variation of the bridge dynamic characteristics; calibrating the acquisition procedures and tools and defining a baseline list of modes for monitoring (i.e. those modes that generally exhibited a significant occurrence over several hours of continuous recording). The above experimental survey (Gentile and Saisi, 2011) clearly highlighted that:

a) a large number of normal modes were determined in the frequency range 0-10 Hz (Figures 7 and 8). More specifically, 4 vertical bending modes and 17 transversal bending modes were identified in the range 0-6 Hz, whereas 3 vertical bending were identified in the range 6-9 Hz;

b) the bridge generally exhibited low values of the damping ratios ($\zeta_i < 1\%$) in both vertical and transverse dynamic response;

c) the vertical bending modes exhibit non-symmetric modal deflections on the upstream and downstream sides of the deck. Since drawings and documents available, concerning both the original design and the refurbishments, do not show any significant lack of symmetry between the two sides of the bridge, the observed non-symmetric mode shapes, revealing a different stiffness of the downstream and upstream sides, are conceivably related with the different state of preservation of the structural elements on the two sides. The observation of the typical corrosion damages, unevenly distributed on structural elements of the deck and the arch, strengthens and corroborates this conclusion;

d) under service loads (road traffic), the natural frequencies of vertical bending modes exhibited slight variations, possibly depending on the excitation/response level (Gentile and Saisi, 2013);

e) the availability of measurement points on both the roadway and the railway deck provided valuable information on transversal deformability of the truss-box girder clearly showing that, as the mode order increases, the two decks exhibited significant relative (and even out-of-phase) transverse motion.

5. The Monitoring System

The dynamic monitoring system was installed on the San Michele bridge during the month of November 2011 and is fully active from November 28, 2011 to April 24, 2015 (Gentile and Saisi, 2010), (Gentile and Saisi, 2015). The system is completely wired and consists of 21 MEMS accelerometers, 7 data acquisition (DAQ) units, 2 thermocouples, 2 Ethernet switch devices and 1 industrial PC. The global arrangement of sensors and hardware components along the bridge is schematically illustrated in Fig 9. The MEMS accelerometers are placed on the railway deck, along seven cross-sections corresponding to the bearings of the truss-box girder between the abutments (Fig. 9), according to the sensor layout adopted since the AVT of March 2010. Each instrumented cross-section is equipped with 3 sensors, in order to measure the vertical accelerations, on the downstream and upstream sides, and the lateral acceleration. The two thermocouples are placed on the second and the fifth cross sections only, one per side in order to measure the air temperature nearby the structure on the upstream and the downstream

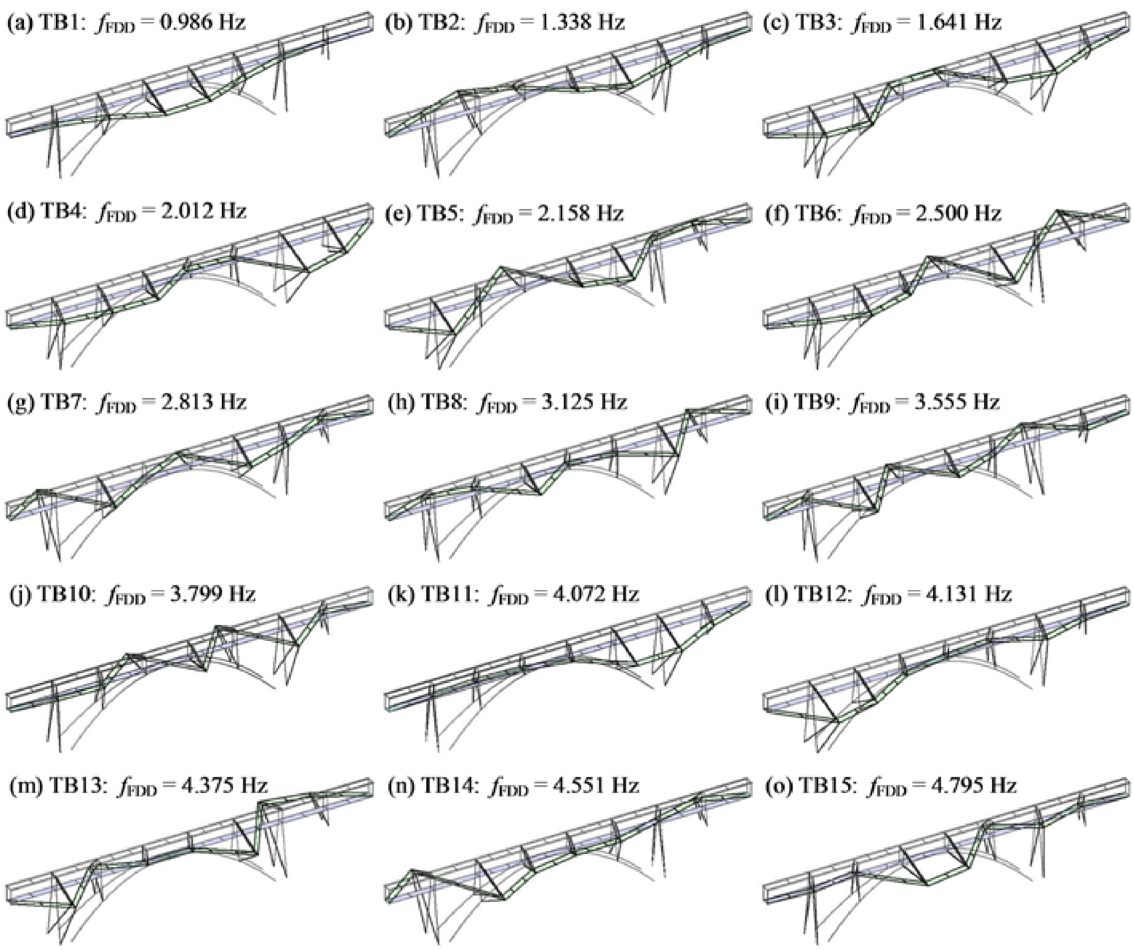

Fig.7: Transversal bending modes generally identified from OMA (14 June 2011, 07:00-08:00) (© Saisi and Gentile)

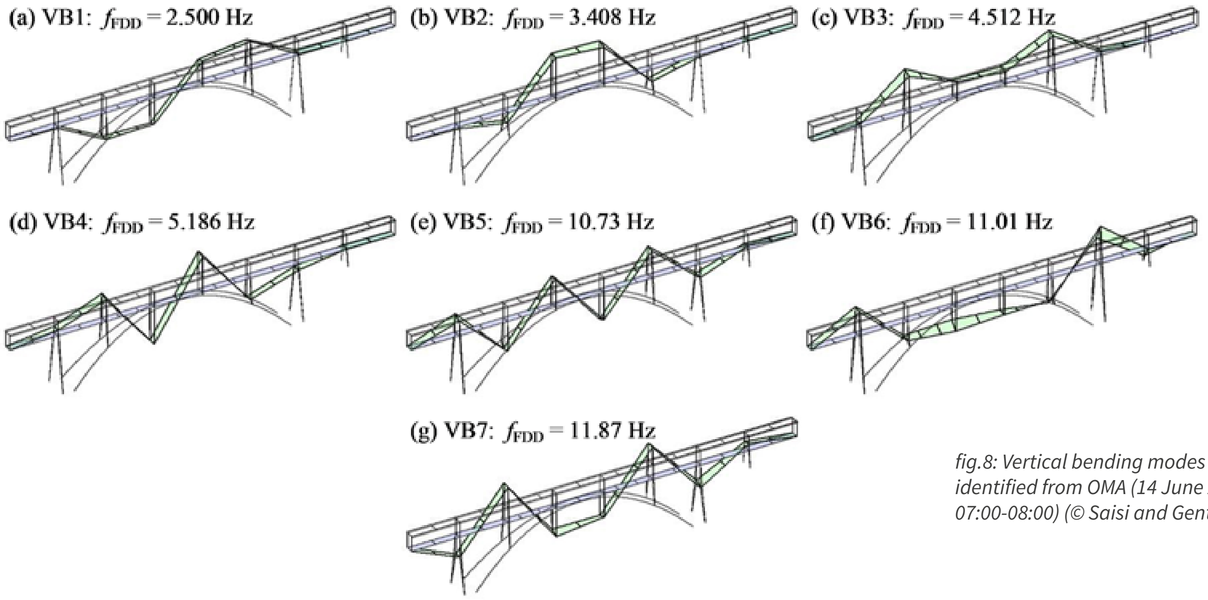

fig.8: Vertical bending modes generally identified from OMA (14 June 2011, 07:00-08:00) (© Saisi and Gentile)

sides, respectively. A dedicated processing software was developed in LabVIEW, including preliminary pre-processing, extraction of the time series associated to the railway traffic only and used for statistical analysis of data and automated modal identification (Gentile and Saisi, 2015).

In the monitoring system, the bridge vibrations due to traffic, wind and other ambient sources are measured and recorded; subsequently, automated operational modal analysis (OMA) is performed to extract the natural frequencies and mode shapes of the structure from ambient vibration data. Once the modal parameters have been determined, they can be used for condition assessment: in fact, the occurrence of damage involves loss of stiffness in some portion of the structure and a corresponding change in the modal parameters.

The aim of the monitoring on the bridge, as well as in similar case studies, is the check of the structural state of preservation through the control of the time evolution of the natural frequencies, distinguishing the effects of temperature and loading. This purpose is particular important for the S. Michele Bridge, where in the previous calibration tests slight but clear fluctuation of the frequency were measured (Gentile and Saisi, 2011), in absence of relevant temperature variation. The first results of the monitoring were accurately checked in order to estimate the possible variation of the modal parameters and defining a baseline list of modes for monitoring (i.e. those modes that generally exhibited a significant occurrence over several hours of continuous recording). The automated OMA tool provided very good results, as all the expected modes (including the closely spaced ones) are clearly identified with the high occurrence.

Furthermore, the work covered has addressed which environmental/operational conditions drive the changes observed in the identified modal frequencies. The natural frequencies of all modes turned out to decrease with increased (road) traffic intensity and the transversal modes are generally more sensitive to the traffic acceleration than the vertical ones. The temperature affects almost all the natural frequencies as well but its effect is non-linear for some modal frequencies and not always characterized by a frequency decrease with increased temperature.

This experimental evidence proved to be of considerable importance for the formulation of alarm protocols. In fact, once removed the temperature effects from the natural frequencies and the „normal“ variation intervals associated with the traffic variability are defined, the lower limits of the identified modal frequencies constitute parameters representative of an alarm threshold for the identification of anomalies or alterations of the current structural conditions. Notwithstanding the quite complex mechanisms that define the normal response of the structure under changing temperature and traffic conditions, multivariate regression models turned out to be appropriate to predict the modal frequency changes of the bridge, given the measured environmental/operational conditions, and to address the SHM strategy of the bridge.

Furthermore, careful data analysis and inspection of frequency tracking, together with the information provided by the mode shapes, allowed to detect structural performance anomalies and changes in the dynamic characteristics of the bridge, conceivably related to the progress of the damage due to corrosion (Fig. 10).

More in detail, data analysis highlighted that: (a) the modal frequency drops were slightly larger than expected and (b) the related standard deviations increased, as well. In addition, the analysis of mode shapes revealed clear changes, as shown in Fig. 18, where the mode shapes of the vertical modes identified on 09/03/2012 (23:00-24:00) and 30/11/2012 (17:00-18:00) are compared.

Figures 10e-f shows that the region mainly involved in the changes correspond to the crown of the arch on the Calusco side of the bridge. Indeed, visual inspection of this region did not reveal any concentrated damage but highlighted that the arch crown exhibits a state of preservation worse than neighbouring regions, with higher corrosion of the structural members. The higher corrosion, detected in the zones affected by the major changes of modes VB5-VB7 (Fig. 10), was conceivably determined by less accurate carrying out the last protective re-painting of those regions, dating back to the late 50's.

6. Structural Model

A 3D finite element model of the bridge was created based on the original drawings, archive research and the intervention design. It is worth mentioning that FE models of the San Michele bridge have been previously developed also by (Nascè et al., 1984), (Nascè, 1993) and (Ferrari and Rizzi, 2008), according only to the original SNOS drawings; however, those models could not consider the subsequent structural modifications of the bridge and its present state of preservation.

FE model of the historic structure, even when based on accurate field survey and mechanical characterization of the materials, always involves simplifying assumptions and several uncertainties in the material, the geometric properties and boundary conditions; in addition, generally the model can be only roughly validated by using few available experimental data. In the case of San Michele bridge, the dynamic identification and monitoring provided effective and accurate validation of the model prior to its use in numerical analysis.

Given the complexity of the bridge and the high number of drawings to be synthesized in the FE model, the numerical model of the bridge San Michele was initially developed working for sub-structures. Hence, independent models were firstly developed for the trussed box girder, the piers and the parabolic arch. Subsequently, the individual sub-structures were assembled in the global model shown in Fig. 11.

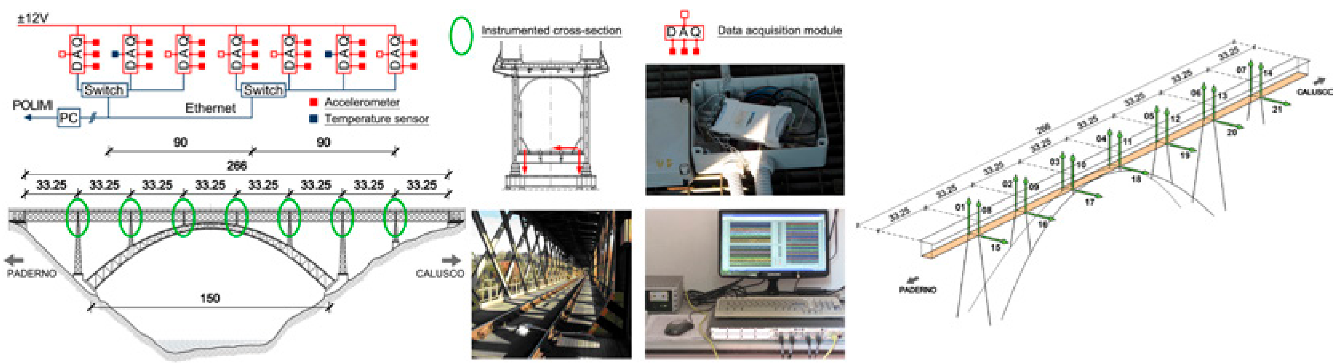

fig.9: Scheme of the monitoring system (dimensions in m) (© Saisi and Gentile)

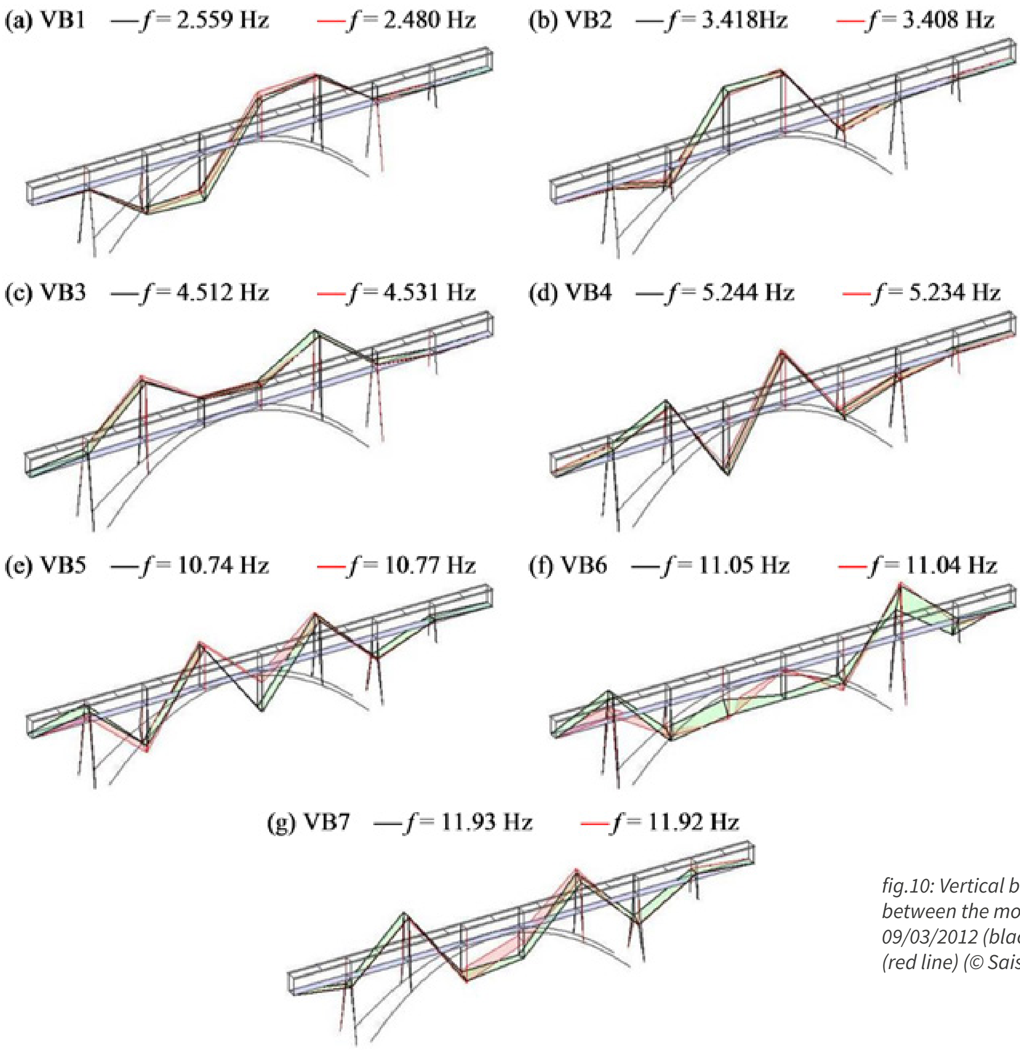

fig.10: Vertical bending modes: comparison between the mode shapes identified on 09/03/2012 (black line) and 30/11/2012 (red line) (© Saisi and Gentile)

In the representation of each sub-structure – where possible – all the metal elements were defined in order to avoid the use of elements of "equivalent characteristics" to describe the components of complex geometry. Only for the arches, consisting of two pairs of trussed arches connected by a high number of lattice elements, a trussed structure of equivalent geometrical characteristics represented each pair of arches in order to limit the number of elements and the degrees of freedom of the model. Furthermore, a simplified representation of the elements connecting the piers to the arch (using elements of high stiffness) was adopted as well.

The complete model of the bridge, obtained by assembling the different sub-structures, is illustrated in Fig. 11 and includes 24564 frame elements, 3992 shell elements, 17026 nodes and a total of 101974 degrees of freedom. The constraints of piers and arches to the reference system were considered as ideal hinges whereas, according to the design performance of the bearings, longitudinal sliding is allowed between the girder and the piers.

Although the phase of implementation and control of the model had been carried out accurately in order to reproduce the geometric characteristics of the bridge, quantitative information was still missing on the mechanical characteristics of the materials and, especially, on the state of preservation and local corrosion affecting piers and arches. Hence, a more accurate correspondence between the dynamic characteristics of the actual bridge and the developed model has to expected by including in the model the results of the survey and mapping of the existing degradation. This would allow dividing the model into the regions that are homogeneous in terms of the state of preservation of the iron materials whereas, at present, only a rough subdivision was introduced by differentiating the mechanical properties of the iron in the upper girder and in the other sub-structures. Although the actual state of preservation of the bridge members was only roughly represented in the model, the dynamic characteristics of the bridge provided a sufficient validation of the FE model. Indeed, the model does not reproduce some experimentally identified modes but it is capable of reproducing a large number of experimentally identified modes with fairly good accuracy (i.e. the absolute percentage differences between calculated and experimental frequencies range between 0.48% and 8.29%, with the mean value of the frequency discrepancy being less than 4.40%).

The FE model has been used to study the static response of the bridge under different load conditions and combinations. Firstly, the effect of the load conditions that characterized the original design and temperature changes ΔT = ± 25°C, and their combinations were considered. The analysis of the results in terms of maximum displacement at the arch crown and maximum axial forces in the upper and lower chords of the arch, allowed to observe the importance of the thermal variations: the effects of thermal changes tend to significantly exceed the effects of live loads, especially in terms of maximum axial force in the upper chord of the arch. This remark seems particularly interesting for the management of the bridge: despite, at present, the service loads are lower (about 40%) than those considered in the original design, it should be kept in mind that the effects associated to the other load conditions, that are always present, are dominant.

Further controls were carried out with several load conditions and combinations and considering distributed load acting on the roadway deck q1b = 15.0 kN/m, as prescribed in the Italian Code DM 04/05/1990 and a real train composed of 1 locomotive E 464 N and 8 wagons, in different positions.

The use of the model to simulate the effects of service loads reveals that the present reduction of the live loads with respect to the design loads (from 90 kN/m to less than 36 kN/m) results in about 10% reduction in terms of maximum displacements and about 18% in terms of maximum axial forces in the arch.

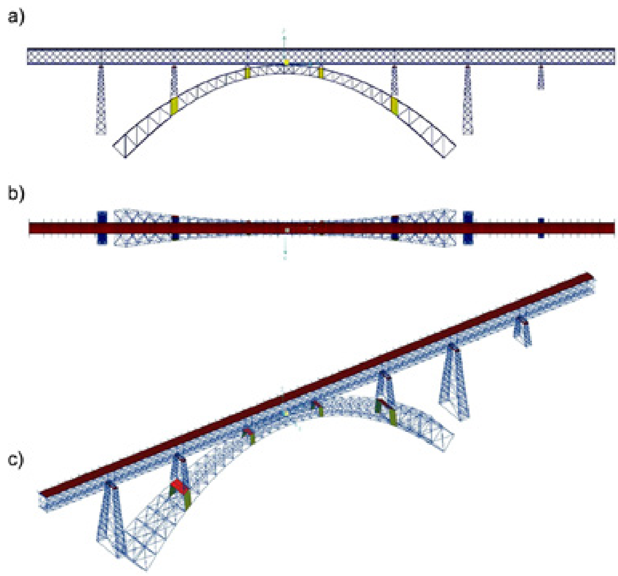

fig.11: Finite element model of the bridge: (a) front view (b) plan (c) and 3D view (© Saisi and Gentile)

7. Conclusions

The study concerns an integrated approach to safeguard an important historical infrastructure, bridging between conservation and security needs. In particular, the careful use of the structure within its capabilities is recognized as a fundamental approach.

The set of questions concerning the state of conservation of the structure has placed as a priority for the Paderno bridge a continuous control, in order to promptly identify pathological changes in the behaviour. The tests and the dynamic monitoring, in fact, constitute a versatile tool of diagnostic synthesis, being able to evaluate the global dynamic characteristics of the structure in a non-destructive way and without involving the closure to the use for long diagnostic campaigns. The experimental evidence promptly identifies any local problems, where to concentrate further inspections and detailed checks.

In this context, the importance of a permanent monitoring system of the structure is evident, pointing out in real time the evolution of the state of conservation of the structure, and to gather the necessary information to proceed with the due clarity to assess the possible scenarios and strategies of use.

The monitoring of a historical structure should be continuous and comprehensive to warn on of changes in the behaviour at an early stage and the necessary interventions.

Acknowledgments

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THE TRUSS ARCH BRIDGE OF MÜNGSTEN IN THE CONTEXT OF THE 19TH CENTURY BRIDGE ENGINEERING

Martin Trautz

The Faded-out Engineer

Last year marked the 120th anniversary of the inauguration of the Müngsten Bridge in the tri-city area of Solingen, Remscheid, and Wuppertal, the highest and at the same time widest spanning steel truss bridge in Germany. With an arch span of 170 metres and a structure similar to the large arched bridges of the Eiffel Company Maria-Pia-Bridge in Portugal and the Garabit-Viaduct in France, the bridge should be a symbol of the technological and economic strength of the re-founded German Empire. The then name 'Kaiser-Wilhelm-Bridge' emphasises the great ambitions, with which the project was being pursued and which had become the subject of numerous legends. One of them is about an engineer, who after the completion of the bridge is reported to have committed suicide fearing that the structure would collapse due to a calculation mistake. Newly accessed historic sources indeed mention a name of an in this context unknown engineer, who was, in addition to the well-known protagonists of Müngsten Bridge Anton von Rieppel (1852-1926), presumably working on the planning and the construction of the Müngsten Bridge in a leading role. By means of facts and forensically accumulated evidence it is proven that such a faded-out-person was indeed involved and – for what reason ever – has been hushed up to the present day.

1. Bridge Design and Construction – High-technology of the 19th Century

Nowadays in times of telecommunication, microelectronics, digitalisation and aerospace engineering, where new and more abstract theoretical findings and their implementation have led to intriguing tools, to us it is hard to believe that iron bridge construction and its methods of planning, calculation and realisation were one of the most significant high-technologies of the 19th century. At that time, it was steelwork that required new calculation methods to ensure planning ability and predictability of the increasingly wider spanning bridges of the fast-growing rail and street network.

Because of its international political and economic pre-eminence as well as its advanced mining industry and iron extraction, the driving fields of the Industrial Revolution, Great Britain was able to realise the idea of a rail-bound transportation most rapidly. In addition to the first locomotive by George Stephenson (1781-1848) many courageous engineers like his son Robert Stephenson (1803-1859), Thomas Telford (1757-1834) or Isambard Kingdom Brunel (1806-1859) developed concepts of wide-spanning suspension bridges, beam bridges and arched bridges crossing rivers and straits, enabling streets and railway to be guided to the remotest places. Telford's chain bridge of 1826 spanning the Menai Strait has a width of 176 metres and represents an impressive start of the construction of large bridges, which drove the younger 'railway constructors' Robert Stephenson to build the Britannia Bridge (1859) which spans 140 metres and spurred Isambard Kingdom Brunel to construct the Royal Albert Bridge (1858) with a maximum width between supports of 139 metres, allowing both to achieve record performances.

On the continent, the development of bridges and bridge design went slower. In France cast-iron arched bridge constructions were built like the Viaduc de Nevers (1853) crossing the river Loire with arches with a span of 43 metres each, as well as wrought-iron bridges functioning as a plate girder like the railway bridge (1852) arching over the river Seine at Asnières, which spans about 32 metres (31,40m). The railway bridge at Moulins over the river Allier built by the steel and bridge construction company Jean Francois Cail in 1858 was a plate bridge and consisted statically of a continuous beam and is therefore statically indeterminate. The first calculation methods for these structural systems came from E.B.P. Clapeyron (1799-1864) who had applied his 'Three Moments Equation' for statically indeterminate structures already for the design of the Seine Bridge at Asnières in 1848.

In Germany since the 50s, the lattice girders were used, implemented as a single beam or as tubular girder. Because of the less pure iron ore, which was available at the Saar, Sieg and Ruhr, in Germany there were problems due to accompanying constituents like phosphor, which severely complicated the manufacturing of large-scale components like plates and complex rolling profiles in terms defects or brittle fracture failures. To guarantee the quality and strength of iron cross sections along with an economic production, it was preferred to manufacture small-sized semi-finished products such as strip iron or angle-profiles and Z-profiles, which then were joined using rivets to form lattice girders. Whilst several large lattice girder structures of the early years were planned by corporate groups of planners, iron suppliers and manufacturer and construction parties, such as the Rhine Bridge Cologne (1850-1859) or the Weichsel Bridge Dirschau (1848-1857), specialised bridge construction companies arose. The oldest one in Northern Germany was Friedrich Harkort in Haspe/Westphalia, in South Germany it was Benckiser Brothers of Pforzheim.

Similar to the French bridge construction companies they designed, worked out and built the iron and steel bridges according to the design of the client's architect or engineer and invented and incorporated thereto efficient construction methods. Competing for the construction of Swiss railway bridges on various routes Benckiser Bros. came out on top of the then competitors several times applying a construction method based on lattice girders, similar to today's Incremental Launching Method. The viaduct across the Worbel Valley near Bern (1856/57) and the viaduct over river Thur at Andelfingen (1857) along the track of the Swiss Northern Railway between Schaffhausen and Zurich were the first bridges which were constructed and erected that way.

Using the launching method minimal means of intermediate or auxiliary supports were needed and it was possible to realise railway bridging unrivalled low-cost and fast. Benckiser received numerous follow-up orders in the German nations, Baden, Württemberg, Hesse and Bavaria as well as in Austria-Hungary and Switzerland and their company turned into the leading bridge construction institution in Southern Germany from 1855 to 1885. Among the best-known bridges are the still existent Rhine Bridge of Waldshut (1859) and the Rhine Bridge of Kehl (1861), both lattice girders were built using Incremental Launching in addition to those of the arched structure of plate girders in Constance (1862) (Fig.2) and the trussed arch structure of the Rhine Bridge of Mainz (1885) (Fig.3) which are also considered well-known.

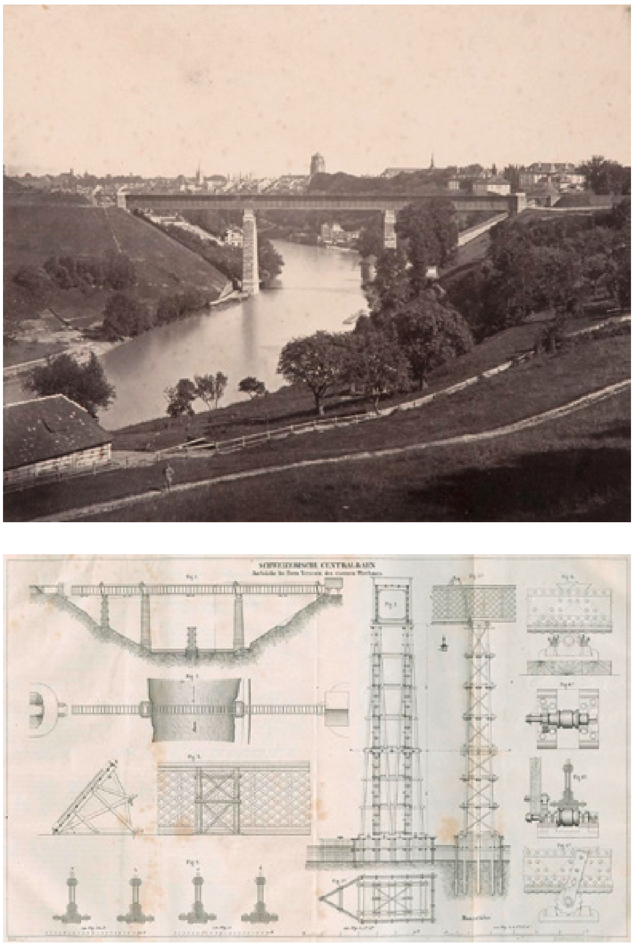

fig. 1: Railway bridge over river Aare near Bern (1858), (© Gebrüder Benckiser)

Other engineers likewise picked up the Incremental Launching method, for instance, Wilhelm Nördlinger (1821-1908) at the construction of the Grandfey-Viaduct over river Saane in Switzerland in 1862. The Viaduct de Busseau (1864) over the river Creuse, which was also build using Incremental Launching, can be dated back to the same engineer, who was originally from Stuttgart and in service of the French railway companies. Nördlinger, the chief engineer of the French Eastern Railways, had drafted the designs of the first two viaducts crossing the Sioule at Neuvial (1868) and at Rouzat (1869) as well, which were the first major project orders of the young Eiffel Company. It is known, that in 1860 Gustave Eiffel (1832-1923) had observed the construction of the Rhine Bridge at Kehl with Incremental Launching.

fig. 2: Road bridge over river Rhine near Constance (1862), (© Gebrüder Benckiser)

fig. 3: Road bridge over river Rhine near Mainz (1895), (© Collection of historic postcards M.Trautz)

In the 1880s bridge construction was set in motion on the Continent: Eiffel got the order for a crossing of the rocky valley cut of the Douros at Porto in Portugal. His corporate partner Theophile Seyrig (1843-1923) had designed an outstanding structure made from steel truss with a sickle-shaped arch, which spanned the main width of 150 metres, most affordable in comparison to the proposals of the competitors. The realisation was successful and with the opening of the Maria Pia Bridge, named after the Portuguese Queen, in 1877 the interest in France in building a similar spectacular structure in their own country had grown.

The planned route from Paris over Clermont-Ferrand to Béziers in the Massif Central, close to Saint Flour over the river Truyère was predestined for such a bridging. The preliminary design similar to the Maria Pia Bridge by Léon Boyer (1851-1886) suited for a direct commission of Eiffel's Company. In this context, Seyrig asked for a better share of the profit of his bridge concept resulting in a conflict and in the separation of the business partners. Eiffel had to find an equal replacement for Seyrig. Through Carl Culmann (1821-1891), who taught at the polytechnic school in Zurich, he was acquainted with the young engineer Maurice Koechlin (1856-1946). Eiffel employed him for the calculation and construction of the 'Garabit-Viaduct' (1880-1884) whence grew a symbiotic and successful cooperation of the two men.

2. Bridge Design Science and Bridge Design Schools

After C.L.M.H. Navier (1785-1836) had published the basic principles of theory of beam structures and theory of material strength of calculations of bridges in 1825 and, based on these, had made calculations of French bridges, the public interest in calculation methods, which effectively made the static qualities predictable was aroused in other countries as well. Not because of his French roots, but because of the excellent mathematical and technical education, Isambard Kingdom Brunel was sent to French College to study engineering. Carl Culmann, born in the Bavarian Rhenish Palatinate, received an education at the School of Applied Artillery in Metz, where he made himself familiar with the methods of the 'Géométrie Descriptive' of Gaspard Monge (1746-1818).

Based on that, he developed a method of graphical analysis for the calculation of trusses and trussed beams, which he published in 1851 and 1852, linked to bridge structures, which he had visited in the United States and had analysed using this own method. Approximately at the same time in Prussia J.W. Schwedler (1823-1894) published a theory of trusses based on an analytical approach. Because these methods initially were only applicable to statically determinate structures Culmann propagated in these publications the realisation of statically determinate structures, calculable with his proposed method. Culman criticised statically indeterminate structures harshly such as lattice girders, invented by the American Ithiel Town (1784-1844) as timber structure, and realised in Germany from wrought iron. Both methods, the graphostatical truss-calculation-method by Culmann and the analytical method by Schwedler allowed the development of optimised bridge structures like 'Pauli Girder' or 'Schwedler Girder'. As discrete methods and unlike the more general approaches of Navier and Clapeyron they offered a precise, in detail analysis of trusses, beam or arched structures and even of the individual parts.

Against this background bridge engineering schools arose in Germany, which propagandised specific ways of calculation and design and criticised other approaches and dissociated from them. The 'Gustavsburg School', founded by Heinrich Gerber (1832-1912), who invented the hinged beam or so-called 'Gerber Girder', was one of those bridge construction schools. It was named after the former 'Süddeutsche Brückenbaugesellschaft Gustavsburg', which was the establishment of the Nuremberg Company Kramer-Klett, afterward MAN, in Gustavsburg near Mainz. It was established in 1862 in the context of the erection of the Mainz Southern Bridge (Rhine Bridge for railway). Heinrich Gerber and his teacher Friedrich August Pauli (1802-1883) were dedicated advocates of statically determinate bridge structures. Gerber's hinge beam bridges are basically continuous beams, becoming statically determinate by introducing hinges and therefore quantifiable with the methods by Culmann and Schwedler.

Statically indeterminate continuous beams, however, if there were no additional hinges inserted, could at first only be calculated using the Three-Moments Equation by Clapeyron in which the stress and tension distribution on the beam section or on the rods of the lattice had to be estimated. Heinrich Gerber once stated: 'Orderliness costs money, but disorderliness even more'. It is no surprise that a calculation method using auxiliary approaches were found dubious and denounced 'disorderly' and improper. In the 1870s and 1880s Carlo Alberto Castigliano (1847-1884) and Heinrich Müller-Breslau (1851-1925) developed methods, with which also highly statically indeterminate systems could be quantified.

3. The Müngsten Bridge – a Showcase of the Wilhelmine Empire

The enthronement of Emperor Wilhelm II. in 1888, the last German emperor, changed the in principle defensive and cooperative attitude of the empire towards the global community to a noticeable more offensive attitude. This can be indicated by the expansion of the naval fleet and numerous associated projects such as the construction of the naval base Wilhelmshaven, the construction of the Kiel Canal as well as numerous railway and bridge construction projects. The Müngsten Bridge, formerly the Emperor Wilhelm Bridge (Fig.4), may also be counted among the high profile and ambitious projects of that time.

So far it was self-evident that the system of the Eiffel bridges Maria-Pia and Garabit was taken on and to which in the meantime were two new and notable variations: The Dom Luiz I. Bridge with a span of 172 meters over the Duoro in the urban area of Porto and the Ponte San Michele/ Paderno Bridge in Northern Italy crossing the river Adda (1889). The Dom Luiz I. Bridge (1886) allows for two bridge levels, an upper level for the crossing of the road and tramway on the leveling of the upper town and a second bridging for the road on the level of the abutment in the valley. This sophisticated design was created by Seyrig, who had developed it on his own authority. It was realised by the Belgian company Société de Willebroeck. Contrary to the Portuguese bridges and the Garabit Viaduct, which are two-hinged arch constructions and therefore one time statically indeterminate, the Müngsten Bridge, as well as the Ponte Paderno, is three times statically indeterminate system. The Italian structure also allows for a level for traffic and a level in the inside of the girder for a line of rails. It was designed and calculated by Julius Röthlisberger (1851-1911), a Swiss engineer and disciple of Carl Culmann.

fig. 4: Müngsten Bridge (1893-1897), (© Werner, 1997)

For the Müngsten Bridge, the ambitions were as to build the construction widely without falsework, solely by using cantilever or cable-stay-construction. To be able to compensate the tolerances in consequence of varying load cases and temperature deformations the bearings were set up to be readjusted. During construction individual bars at the bearings and at the arch crown were left out according to plan and were added later by means of hydraulic presses at completion, whereby the bridge became its statical indeterminacy. All iron profiles and cross sections were made from basic, by means of the Thomas process extracted, Mild Steel, which was in Germany until then rarely used. Therefore, comprehensive material tests regarding ductility were conducted during construction.

For transport and hoisting of component parts Bredt cranes were used, which were controlled electrically and operated with variable counterweights and therefore induced smaller loads on the supports. The calculations were conducted using several methods, graphostatically and analytically, and in 1904, seven years after the opening, a presentation structural analysis was published in book format by Wilhelm Dietz (1850-1921), a professor at the Technical University of Munich . On the part of the Süddeutsche Brückenbauanstalt, Gustavsburg, Anton von Rieppel (1852-1926) (Fig.9b) was generally recognized as the author of the Müngsten Bridge. The legend of an engineer, who in the course of the opening of the bridge is reported to have committed suicide, seems given the protagonists v. Rieppel and Dietz like a legend, which does not bear any reference to the project or its course.

fig. 5: Bronze plate with protagonists under Müngsten Bridge.

4. Other Protagonists

As expected, there were a number of additional protagonists, who contributed to the Müngsten project. The bronze plate of the memorial stone (Fig.5), which was erected below the Müngsten Bridge, lists the key data of the building, the involved institutions as well as the executive personnel . The MAN-director Anton von Rieppel and Professor Wilhelm Dietz are mentioned first among the contributors of MAN . Among the other participants, engineers Bohny, Herrman and Möbus, the name Bilfinger is apparent. It points to an engineer's dynasty of the 19th century, which is connected to the company names of 'Grün the company history of Benckiser Bros. from Pforzheim, the name Bilfinger appeared as well and referred to Bernhard Rudolf Bilfinger (1829-1897) (Fig.6a), the chief engineer of the 1888 shut-down company. He had contributed from 1849 to its closing down in 1888 to practically all projects, especially to those of large bridges.

After that, he had actually changed over to the Southern German Bridge Construction Company Gustavsburg (Süddeutsche Brückenbauanstalt, Gustavsburg), which was part of the 1907 founded MAN (Maschinenfabrik Augsburg Nürnberg). Bilfingers son Paul Bilfinger (1858-1928) was a co-founder of Grün und Bilfinger and was born in Bern during the construction of the large railway bridge over the Aare (Fig.1), which his father managed. The second son, Bernhard Karl Bilfinger (1862-1924) (Fig.6b), had worked for Benckiser as a bridge engineer a couple of years until 1887 and had changed over to the Southern German Bridge Construction Company Gustavsburg. Bernhard Karl was born in Constance during the construction of the road bridge over the river Rhine (Fig.2). In the Benckiser's family chronicle, it can be read: `Bernhard Rudolf Bilfinger left on the 1st of November 1888 after 39 years the firm Benckiser and changed to Gustavsburg'. In this source as well as in B. Körner's 'German lineage register' volume 10 (Körner, 1903), are Bernhard Rudolf Bilfinger and his son Bernhard Karl Bilfinger attributed the position of first and second directors. According to this source was the Müngsten Bridge the last work of the father Bernhard Rudolf. The son Bernhard Karl is said to have worked on the outstanding projects of the Bridge (Fig.7) over the Kiel Canal and the Wuppertal Suspension Railway.

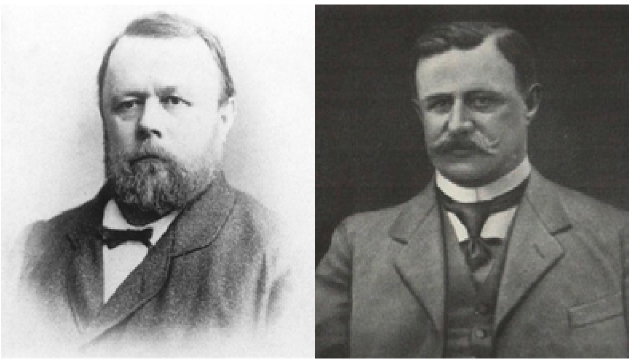

fig. 6: a) Bernhard Rudolf Bilfinger (1829-1897) b) Bernhard Karl Bilfinger (1862-1924)

fig. 7: Road and Rail bridge over Kiel Canal (1883).

The time in which Bernhard Karl had left Benckiser and had changed to the Southern German Bridge Construction Company Gustavsburg was a time, in which the project situation had worsened. In the years before 1885 Benckiser was very successful and acting internationally. However, from 1880 the competition in the iron bridge construction business increased tremendously. From 1863 on the machine factory Esslingen, previously specialized in locomotive and railway equipment, focused on bridge construction as well. In the Rhine and Ruhr area, it was the Gutehoffnungshütte ironworks and the Dortmund Union, who pushed for the iron bridge construction and railway bridge construction and were, compared to sole fabricators such as the Benckiser company, at an advantage because of their own iron production. This had been confirmed by the competition of the Friedrich Bridge in Mannheim in 1887, which was won by Benckiser Bros. and Bernatz & Grün, responsible for the foundations and solid structure. The city of Mannheim, however, did not commission Benckiser, who won first place, but the runner-up team with the Southern German Bridge Construction Company, for which von Rieppel was supposed to be the designer, which was quite similar to the Benckiser bridge proposal.

5. Curiosities and Contradictions

Aside from the fact that the name 'Bilfinger' in monographs or chronicles of the Southern German Bridge Construction Company or the subsequent MAN practically does almost not appear, it should be noted that Anton von Rieppel all the more got glorified as outstanding engineer and entrepreneur in one as well as a saviour of first the Bridge Construction Institution Gustavsburg and later of the head office in Nuremberg and as creator of the industrial corporation MAN. His great gift for bridge engineering was much talked about and all bridge and building projects of the Bridge Construction Institution Gustavsburg after 1885 invariably were ascribed to him. V. Rieppel joined Heinrich Gerber as a young engineer in Gustavsburg only in 1876. In 1877, at the age of 25, he was appointed workshop supervisor until in 1884 through the preliminary closing of the Bridge Construction Institution because of losses a temporary halt in production set in. After that, from 1885, according to the company chronicles, v. Rieppel is said to have rebuilt the factory Gustavsburg as director together with Wilhelm Dietz. Presumably because of the success at the competition of the Friedrich Bridge over the Neckar in Mannheim (Fig.8) from 1886/87 he was appointed in 1887 at the age of 35 as a second director of the head office of the machine construction institution in Nuremberg. For that reason, Bernhard Karl Bilfinger was taken on by the Southern German Bridge Construction Company at the same time to contribute to the design and the calculations of the Mannheim Bridge (Schwarz-Pich, Karl-Heinz, 1912).

fig. 8: Road bridge over river Neckar in Mannheim (Friedrichsbrücke) (1887-1889).

With the bankruptcy of Benckiser in 1888 Bilfinger's father, Bernhard Rudolf, an absolutely extraordinary experienced bridge builder of the time, was also engaged by the Southern German Bridge Construction Company as the first director of the firm. From then the Southern German Bridge Construction Company had a powerful and skilled bridge engineer team with extensive experience and great connections to potential clients. This way v.Rieppel could leave Gustavsburg in 1889 and pursue his assignments as a member of the board of management and designated director of the Maschinenanstalt Nürnberg in Nuremberg.

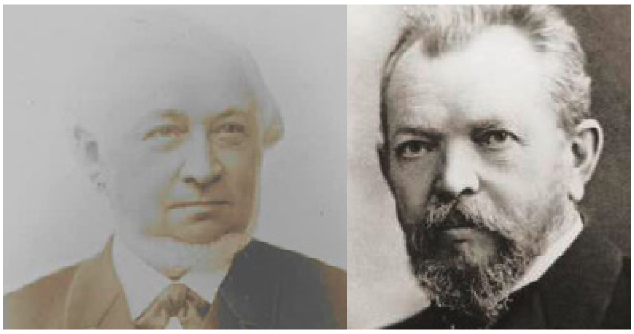

fig. 9: a) Friedrich Hensolt (1830-1894), director of Maschinenbauanstalt Nürnberg between 1873-1892 b) Anton v.Rieppel (1852-1926), director of M.A.N. (© both: MAN Archiv Augsburg)

All these personnel decisions in Gustavsburg and Nuremberg were made by Friedrich Hensolt (1830-1894) (Fig.9a), then director of the corporation in Nuremberg. He wanted to make sure that the restart of the Southern German Bridge Construction Company would be successful and that even in Nuremberg a young, committed director would stand by his side after the old technical directors Hilpert and Reuschlein had retired (anonymous, 1930). Due to Hensolt's premature withdrawal from the management at the end of 1892 due to increasing health problems, the constellations changed again and at the age of 40, Rieppel became the sole managing director and director of Maschinenbau AG Nuremberg.

In MAN's company chronicles, however, the process and events are presented differently: There it is reported in an almost narrative style that v. Rieppel did not like to move to Nuremberg because he felt so committed to building bridges. For this reason, the Gustavsburg office moved with him to Nuremberg in 1889 and was relocated back in 1901, after the opening of the Wuppertal suspension railway. One inevitably wonders what would have been the point in relocating the technical office several hundred kilometres away from the workshops and project sites during the planning and construction phases of two such important projects as the Müngsten Bridge and the Wuppertal suspension railway.

The role of Wilhelm Dietz, the other supposedly responsible engineer, is also curious. He was a professor of structural analysis at the Technical University of Munich and had just published a book on 'Mobile Bridges' (Dietz, 1897) in the opening year of Müngsten Bridge, in 1897. Seven years later, in 1904 a book of the statical calculations of Müngsten Bridge (Dietz, 1904) was edited by him. Apart from the Müngsten Bridge, no other significant bridge structure (Mehrtens, 1900), (Mehrtens, 1912) is officially attributed to him. This raises the question of how he could have been entrusted with the statics of the Müngsten Bridge, when he was based in Munich, participating in university teaching and at the same time involved in editing a special book on bridge constructions of a quite different kind than that of the Müngsten Bridge. Rather, one expected, that Dietz or one of his assistants would have published a technical report or something similar in his name about the calculation of such a demanding construction as the Müngsten Bridge. It also remains unclear why there was a show book of statical calculations of Müngsten Bridge at all, which was published so much later after the opening. Dietz was the sole editor and author of the book, although many others (Castanjen, Bohny, Möbus, v. Rieppel) are mentioned in the chronologies, who are said to have been involved in the design and the structural analysis of the bridge. In any case, Dietz was the only one of the protagonists who, according to the report of the Centralblatt of Building Administration of that month (anonymous, 1897), was not present at the celebration on the occasion of the completion of the Müngsten Bridge on March 22nd, 1897 on the Emperor's birthday.

A closer look at the distribution of roles of the other participants and their competences in planning reveals further contradictions and curiosities: The engineer Max Castanjen (1856-1934), initially working for the railway authority, for example, was responsible for the competition and the submission of proposals for Müngsten Bridge. He is said to have created the design for the Müngsten Bridge (Walbrach, 2006), and also reviewed the structural analysis and, according to Centralblatt, 'carried out a large part of the basic calculations himself' (anonymous, 1897). In a previous report, also in the Centralblatt of Building Administration (Castanjen, 1895), on the development and selection of the bridge concept for the Müngsten Bridge, which Castanjen wrote himself in 1894, he presents the three bridge concepts proposed for construction. There were a so-called 'Scaffolding Bridge', a 'Cantilever Bridge' and the steel truss arched bridge, which was ultimately built. According to this report, the first two drafts had been proposed and technically elaborated by the Gutenhoffnungshütte and Friedrich Harkort company respectively. The design of the widespan arched bridge originates from the Southern German Bridge Construction Company (Castanjen, 1895, p. 162, section 3). Castanjen had therefore not even authored the design for the Müngsten Bridge himself but had given the applicants only possible structural concepts, which were preferred by the authority. In the context of his role as a reviewer of the proposals, it may be understandable that he himself has carried out fundamental calculations. Nevertheless, however, the binding and detailed structural calculations relating to the construction to be executed – as is still customary today – were carried out by the chief engineer of the executing company.

As of April 1st, 1895, Castanjen himself changed to MAN's Nuremberg office, even during the Müngsten Bridge project in 1895. There he is said to have worked on the Wuppertal suspension railway. At that time, however, Bernhard Karl Bilfinger was already demonstrably working in Elberfeld on the project planning of the Wuppertal suspension railway as a project engineer. This can be seen from a letter from Anton Rieppel to Bernhard Karl Bilfinger dated 28.5.1895 (Bilfinger), where Rieppel decidedly praises Bilfinger's work and grants him an annual salary of 9000 RM/year to continue his work in the known, efficient way. Also, in the following year 1896 Bernhard Karl was still in Elberfeld, his son Wilhelm (1896-1975) was born there on the 1st of September. According to the letters (Bilfinger, 1895 and 1897), he remained in Elberfeld until his retirement from MAN in 1897. In May 1896, MAN patented under the number 91642 a 'structure for suspension railways' (Kaiserlicher Patentamt, 1896), a support structure, which is also called 'Rieppel-Girder' (Rieppelträger) (Walbrach, 2006) in later publications. When the patent document is examined, the applicant is MAN, but there is no explicit mention of one or more individuals as inventors as it is typical for a patent referring to an individual. As far as the other engineers named on the plate (picture 5) are concerned, the engineers were very young at that time. Friedrich Bohny (1867-1939), for example, who later managed the Gutehoffnungshütte as director, earned his spurs at the time of the Müngsten Bridge - as Gottwald Schaper writes in the obituary (Schaper and Friedrich, 1939).

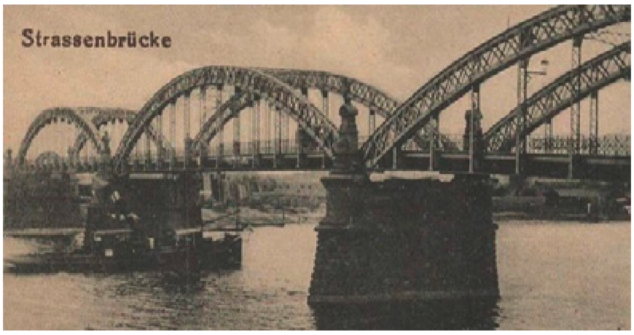

fig. 10: a) Road bridge over river Main in Kostheim (1889-1890). b) Road bridge over river Danube in Straubing (1896).

6. The Bilfingers and the Southern German Bridge Construction Company

When Bernhard Karl Bilfinger and Bernhard Rudolf joined the Southern German Bridge Construction Company in 1887 and 1888, they brought with them an undoubtedly desired and lasting boost of experience and innovation in terms of project size, construction methods and new bridge systems such as arched structures. Previously, the Southern German Bridge Construction Company had gone through difficult years with a rather meagre order situation and had acquired projects almost only 'on its doorstep', i. e. in Bavaria and Franconia, so that it had to close in 1884. Heinrich Gerber is said to have put off many potential clients because he insisted that the choice of the load-bearing system and construction must be left to the engineers from Gustavsburg alone. Since not every client wanted to realize a Gerber or Pauli girder a priori and since other designs, arch bridges, for example, had been established in the meantime, it was preferable to look for another construction company. The spectrum of bridge construction systems from Gustavsburg was thus limited. However, since 1888 and even before the Müngsten Bridge was built, the Southern German Bridge Construction Company erected several outstanding arched bridge constructions: The Main Bridge near Kostheim (1889-1890) (Fig.10a), the road and railway bridge over the Kiel Canal near Grünenthal (1891-1892) (Fig.7) and the road bridge over the Danube near Straubing (1895-1896) (Fig.10b). In the Körner's (Körner, 1903, pp. 83 and 88) and in the Badische Biography (Schwarz-Pich, 1912) the Grünenthal Bridge is decidedly attributed to Bernhard Karl Bilfinger as a spectacular bridge design, for that he was far later, in 1914, honoured with the Prussian ‘Rote-Adler-Orden, IV Klasse’. The Main Bridge Kostheim with its arches bears a clear resemblance to the Mainz Rhine Bridge (Fig.3) and the Danube Bridge Straubing (Fig.10b) with its crescent-shaped arches fits seamlessly into this series of arch bridges in 'Bilfinger's handwriting'.

7. The Faded-out Engineer

Even this apparent work of the two Bilfinger engineers did not lead to them being mentioned within MAN or to reminiscence in the company chronicles. While even more information on Bernhard Karl was passed on in various literature, his father Bernhard Rudolf Bilfinger seems to have virtually disappeared in terms of his work outside and inside MAN. Thus, nothing more than an obituary notice can be found in the company archive.

The Müngsten Bridge was completed as planned for the birthday of Emperor Wilhelm I. on March 22nd, 1897; the bridge was opened on July 15th, 1897. Bernhard Rudolf Bilfinger celebrated his 68th birthday shortly afterward, on August 4th, and died on August 26th, 1897(Körner, 1903), almost six weeks after the bridge was opened from a stroke. In Körner's Biography (Körner, 1903) the place of death is specified as 'Gustavsburg near Nuremberg', i. e. Gustavsburg. Thus, he had not committed suicide, but died a completely normal death, coincidentally shortly after the completion of one of his most important works, the Müngsten Bridge.

Nevertheless, it remains unusual and surprising that Bernhard Rudolf Bilfinger, who may have been a modest and reserved character, but was not an unknown person among experts, was in no way honoured for his life's work after his death, neither by the company nor by colleagues or bridge building experts, except the mentioned biographies (Benckiser), (Körner, 1903). Other forms of honouring, such as the composition of an obituary for a deceased and deserving engineering colleague in a specialist journal, as was common practice at that time, are completely absent. Even in that MAN obituary (Gebrüder Benckiser) notice, one does not mention Bilfinger's particular merits in any way but is content with a generalizing phrase: 'With the deceased we lose one of our most loyal, devoted officials, who with his unusually large experience was one of the most valuable support of our company'. While there Bernhard Rudolf Bilfinger had been attested to his 'unusually large experience' and his activity as 'technical director of many years', Bernhard Rudolf, the full name by which he distinguished himself from his son as a further member of the company was left out. Was it intended that his identity should not be clearly recognizable?

8. Under the Veil of Silence

The general and universal secrecy with regard to Bernhard Rudolf Bilfinger's entire professional environment – also in the ranks and personal connections of his sons – could be associated with a problem or a mistake. A mistake that would have put a strain on the Müngsten Bridge project or the guild of the engineers of that time and discredited the building project, which would have undermined the great ambitions with which it was associated. But what was that supposed to be? The project was eventually completed on schedule and to the satisfaction of all parties involved. In his report of August 1894 (Castanjen, 1895), Max Castanjen also suggested the scheduled planning. At that time, the brickwork of the foundations was nearing completion and it was intended to start building the pillars in the autumn of 1894, to complete the entire steel construction in the following year and to complete the project at the beginning of 1896. As we know, the project took about one year longer. In the subsequent issue of the 'Centralblatt' of the Construction Administration (anonymous, 1897) of March 1897, it is actually reported that the erection of the iron pillars was not begun until April 1st, 1895. Furthermore, unfavourable circumstances are reported, under which the construction work was carried out during the winter of 1896/97, obviously, in order to be able to keep the Emperor's birthday as the first date of inauguration. Apparently, the steel construction work was very much delayed. Reasons are not given. In this respect, another, quite probable legend around the Müngsten Bridge gains relevance. It tells the story of bridge and arch components that had not properly matched at the crown and therefore had to be dismantled. In view of the time differences regarding the beginning of the steel construction work, such an interlude seems quite plausible. Also, the problem of insufficient fit of components is much more likely to occur in a statically indeterminate system such as the Müngsten Bridge than in 'conventional', i. e. statically determinate systems. Solely due to the extensive, multi-part construction and the topography of the relatively deeply carved valley with a position close to a north-south axis, a wide variety of different temperature effects could have been generated on the building components during the course of the day alone and have led to such problems. Since a major part of the workforce would have been affected by a dismantling and these would have become witnesses, this legend is to be ascribed a high claim of truthfulness.

If Bernhard Rudolf Bilfinger held the position of technical director, he was probably blamed for such problems and degraded to an ordinary engineer as he is titled in the report about the inauguration ceremony in 1897 (anonymous, 1897) and on the memorial plate under the Müngsten Bridge (Fig.5). A letter from Paul Bilfinger to his brother Bernhard Karl dated September 5th, 1895 (Bilfinger) mentions a new technical director who, according to the Wormser newspaper, had been hired in Gustavsburg. Who the new director was is not mentioned in the letter. Certainly, one tried to cover up an incident with dismantling and the like. It would have been extremely embarrassing if it had become known that with such a daring venture, the ends of the arch would not have met and that mistakes would have occurred. Considering such a situation, which was attributed to their father, Bilfinger's sons were also obliged to exercise restraint. Perhaps it was also feared that the discovery of such an incident could have caused the public's doubts about the innovative and ambitious design of the Müngsten Bridge, as well as doubts about the engineers involved in the project. It may, therefore, have come to some sort of 'silent consensus' to spread a veil of silence over such difficulties.

Apart from these scenarios and possible accusations: From these facts and aspects it becomes clear that Bernhard Rudolf Bilfinger and Bernhard Karl Bilfinger at Southern German Bridge Construction Company were never really integrated into the company community despite their many years of activity. With the resignation and subsequent death of director Friedrich Hensolt in 1894, the two apparently lost their mentor in management. In 1893 Bernhard Karl Bilfinger married Hensolt's daughter, right before her father died on August 1st, 1894 from the consequences of his illness. Obviously Bilfinger junior had established a good personal relationship with the directorate of the Maschinenanstalt Nürnberg. It seems that v. Rieppel as director of the corporation liked to use the services of the Bilfinger engineers and was

– according to the correspondence (Bilfinger, 1895 and 1897)– on familiar terms with Bernhard Karl. Nevertheless, after the death of Bernhard Rudolf in August 1897, he hired another person as technical director in Gustavsburg called Fischer. Bernhard Karl was only offered the position of deputy in Gustavsburg at the beginning of 1898 (Bilfinger, 1895 and 1897). Bilfinger junior rejected after long consideration and changed to his brother Paul Bilfinger at Grün and Bilfinger in Mannheim.

V. Rieppel as director of M.A.N seemed to be anxious for preserving the honour of the 'Gustavsburg School', to which he counted himself. For this purpose, he used mistakes made during the work and thus ensured that the 'Non-Gustavsburg engineers', particularly Bernhard Rudolf Bilfinger would be put to oblivion in the years after his death. As Bilfinger senior's complete professional background disappeared already in the 19th century with the closure of Benckiser Bros. and the death of his former boss August Theodor Benckiser (1820-1894) the veil of silence did cover not only his work for 'Gustavsburg' but was drawn over his entire professional work as a bridge engineer.

As the evaluation of MAN's chronicles and monographs shows, they were not afraid to change details of the company's history, timelines and roles or the biographies of protagonists. The above-mentioned responsible engineers Dietz and Castanjen were - if at all - actually only temporarily involved in the bridge construction project, while the other officially involved engineers belonged to a younger generation of engineers who had limited experience in iron bridge construction compared to Bernhard Rudolf Bilfinger. Max Castanjen, who had transferred from the Elberfeld Railway Directorate to MAN in 1895, did not himself make a demonstrable contribution to the development of the technical concept of the Müngsten Bridge, nor was he involved - at least until 1897 - in the design of the Wuppertal suspension railway.

The sum of inconsistencies, the apparently intended distorted representation of the roles of the participants, according to which the young engineers were in charge, organized and calculated the project, and thereby were only temporarily present, whereas the only 'old engineer' with his extensive experience had to keep the 'depot in Gustavsburg' in order , indicate a cover-up campaign. This campaign helped v. Rieppel to create with the project achievements of the concealed engineers and directors in Gustavsburg a superhuman image of himself , who seemed to be able to achieve technological excellence as an engineer as well as organisational records as a manager at the same time. This image ultimately contributed to his incomparable advancement not only to the highest levels of the company but also to the professional world and the society at that time when he was ennobled in 1906. Apart from that v. Rieppel tried to foster the other engineers named in the context of the Müngsten Bridge as the new generation of 'Gustavsburgers', whom he had chosen himself.

9. Conclusions

Legends are stories that are most often not written down but are kept alive for generations and sometimes for centuries. Legends arise among humans from fragments of events or appearances and they demand explanation or resolution. As long as these do not exist, they continue to exist. The legendary engineer, who is said to have plunged himself to death because of a mistake in the calculation of the Müngsten Bridge did not exist, but a 'faded-out engineer', who at the end of the project fell into oblivion. This was not a small frightened technician on the fringes of the project, but one of the most experienced bridge building engineers of the 19th century: Bernhard Rudolf Bilfinger. It is safe to assume that he was the one, who strongly, if not even primarily, shaped the design and concept of the Müngsten Bridge as a chief engineer.

In view of his extensive experience and expertise, it was certainly he, who made the connections during the Müngsten Bridge project. He must have assigned the tasks to the young engineers and discussed with the experienced engineers the procedure for the construction, the structural analysis or the elaboration of the construction methods. In a 'carousel' of numerous and alleged protagonists of the project, Bernhard Rudolf Bilfinger was the only and most important personnel constant during the entire course of the project from 1891 to its completion in 1897. He had learned and acquired this role and competence at Benckiser in 39 years in the course of several medium and large bridge building projects and precisely for this reason he was hired by Friedrich

Hensolt and the Maschinenanstalt Nuremberg as technical director of the Southern German Bridge Construction Company in 1888. But this role made him vulnerable when problems or mistakes arose.

It is possible that when constructing the Müngsten Bridge this was exactly the cause of his downfall and caused him to draw a veil of silence and oblivion, not only over his achievements for Gustavsburg but also over his even more extensive work from his previous activities at Benckiser Bros and thus his entire life's work. According to his biography (Körner, 1903), Bernhard Rudolf Bilfinger had built eight bridges of river Rhine and many more over big rivers in Germany Switzerland, Austria, and Bohemia. The archives around the Benckiser company (Gebrüder Benckiser) reveal even more than 50 steel bridges, which were designed and built by Bernhard Rudolf Bilfinger.

In this tragedy of oblivion, Anton v. Rieppel was given the less glorious role of the antagonist. He felt compelled to use and employ the two Bilfinger engineers, who his predecessor Friedrich Hensolt, director in Nuremberg, had engaged. Although according to the sources (B.K.Bilfingers letters 1897), he had collaborated and communicated with Bernhard Karl Bilfinger in connection with the Wuppertal suspension railway and other projects, he did not support him with regard to his goal of becoming a 1. technical director in Gustavsburg. It may have touched his pride as a genuine 'Gustavsburg disciple' of Heinrich Gerber and frustrated him that the representatives of another bridge engineering school, the 'Benckiser School' with a much more pragmatic approach, could be so successful in Gustavsburg. And thus, one has to assume that the many curiosities and contradictions in the facts and procedures around Gustavsburg and around the Müngsten Bridge or the Wuppertal suspension railway had been smudged and manipulated in the company chronicles at v. Rieppel's instigation.

Some of the individuals associated with the Müngsten Bridge could have been active in the project in the same or similar roles as they were indicated there, but the superiorly responsible engineer could not have been director v. Rieppel in Nuremberg, who was busy with the reorganisation and fusion of the Nuremberg machine factory and the establishment of the diesel engine at the same time. It could have neither been Professor Dietz in Munich, who had many other obligations to fulfill, but it must have been Bernhard Rudolf Bilfinger because of his superior competence. The concealment of B. R. Bilfinger's true role was to ensure that the expert public accepted that v. Rieppel was the 'Maker of Müngsten Bridge'. V. Rieppel abused his power as a director in order to avoid having to hand over the most spectacular steel construction projects of the time in the today Wuppertal and Westphalia, to be able to exploit them for his own reputation. The fact that he accepted to erase the reputation of a highly deserving and technically superior colleague when adopting the projects and not to rehabilitate him after a few years or decades, does not cast a good light on his character. Anyway, these investigations do not aim to diminish the merits of Anton von Rieppel, which seem to lie all the more in the area of management for MAN than in the field of engineering. The aim of these investigations is to rehabilitate Bernhard Rudolf Bilfinger, a forgotten but outstanding bridge engineer of the 19th century, who is to be mentioned with names like M. Koechlin, J. Röthlisberger, Th. Seyrig, J.W.Schwedler or with Heinrich Gerber in one breath.

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CHAPTER 4:

EXCURSE: THE SIGNIFICANCE OF THE VARIOUS ARCH BRIDGES FOR ADJACENT MUNICIPALITIES AND REGIONS

THE MÜNGSTEN BRIDGE – A SYMBOL OF IDENTIFICATION IN THE TRI-CITY AREA OF SOLINGEN, REMSCHEID AND WUPPERTAL

Michael Kloos and Carsten Zimmermann

Abstract

The Müngsten Bridge can be in many ways considered as a technical pioneer- and masterwork. Completed in 1897, it is the highest and at the same time widest spanning steel truss bridge in Germany up until nowadays. Probably for the first time scientific calculation methodologies were applied systematically when the bridge was built. Thus, the bridge can be seen as a precursor of modern bridge building technologies.

But there is also a second layer of the importance of Müngsten Bridge. When the bridge was erected at the end of the 19th century during the period of the Second Industrial Revolution the re-founded German Empire had great ambitions to become a powerful nation in Europe. The bridge, then called 'Kaiser-Wilhelm-Bridge', was conceived as a symbol of the technological and economic strength of the German Empire. Due to this combination of innovative technological solutions with a symbolic role in the German Empire the bridge became both the subject of numerous legends and a strong symbol of identification in the tri-city area of Solingen, Remscheid and Wuppertal ('Bergisches Städtedreieck').

This paper attempts to summarise major aspects of these combined technological and symbolic features of Müngsten Bridge so as to clarify which role the intended transnational World Heritage nomination could play in this context.

Keywords: Steel Truss Arch Bridge; German Empire; tri-city area of Solingen, Remscheid, and Wuppertal; UNESCO World Heritage

fig. 1: Müngsten Bridge under construction (© Deutsches Museum, München)

1. Introduction

The Müngsten Bridge has been erected in order to cross the valley of the river Wupper between 1893 and 1897 by a group around the engineer Anton von Rieppel (1852-1926) and the Maschinenbau A.-G. Nürnberg (today Maschinenfabrik Augsburg Nürnberg, MAN). Due to the erection of Müngsten Bridge, the existing railway link between the cities of Remscheid and Solingen was shortened considerably. Though the direct distance between the two cities is only 8 km long, prior to the construction of the bridge the connection between Remscheid and Solingen required a considerable deviation of approximately 44 km. Hence, Müngsten Bridge became a central infrastructural element of the industrial tri-city region of Solingen, Remscheid and Wuppertal ('Bergisches Städtedreieck') which is characterised by a particularly hilly topography and a highly specialised and export-oriented industrial structure for tools and blades.

With a height of 107 m and a span of 170 m, Müngsten Bridge is the highest railway bridge and the truss arch steel construction with the largest span in Germany until nowadays. The sustainable construction of Müngsten Bridge made it possible to use it 120 years without greater interruptions in its original purpose as a railway viaduct. During this period of time, the bridge could be upgraded with regard to particular requirements of the railway traffic without far-reaching transformations of its load-bearing structure. Only in recent years, major maintenance works were necessary. Construction, aesthetics, and characteristics of Müngsten Bridge are therefore conserved nearly authentically and the use of the viaduct for regular railway traffic will also be possible in the future. Similarly, elements of the building process, such as Schaberg station, the assembly area for pre-fabricated elements, as well as the Windfelner Bridge which served as an element to deliver construction materials are preserved up until nowadays on their original locations.

Today, Müngsten Bridge is one of the very rare still conserved steel truss arch bridges on a large-scale dating from the second phase of the Industrial Revolution at the end of the 19th century. It is also the oldest preserved mild steel bridge in Germany. Due to these particular values, Müngsten Bridge is listed as a monument since 1985. Besides, the Regional Agency for Monuments Preservation in the Rhineland ('LVR-Amt für Denkmalpflege im Rheinland') has listed the bridge as a monument of national importance in 2011.

2. Müngsten Bridge as a milestone of technological innovation

The Müngsten Bridge can be considered as a milestone within the development of European bridge building technique since its construction and building technology merged the know-how of various European schools of engineering and bridge construction companies at its time. Besides, innovative construction materials such as mild steel ('Flussstahl') were used to build the bridge. Presumably, new calculation methodologies such as the 'Theory of the Elastic Arch' ('Theorie des Elastischen Bogens'), which was published in 1879, have been applied for the first time during the construction of Müngsten Bridge. This lead to the innovative three times statically determined main load-bearing construction of Müngsten Bridge. Both parts of the trussed arch were erected as cantilevered curved beams supported by cable stays ('Rückspannseile'). Thus, the bridge could be built as a cantilevered construction. This construction system made it possible to erect the trussed arch without any support of costly scaffoldings. Consequently, the construction of Müngsten Bridge marks the introduction of cost-efficient construction technologies which are used up until nowadays. It is likely, that it served as an example for a large number of similar constructions in Europe and the U.S. Hence, it can be considered as a pioneering work of steel technology at the end of the 19th century.

In comparison to truss arch bridges erected earlier by the French company Eiffel the construction of Müngsten Bridge is more filigree. This fact which points to both the sophisticated engineering under integration of scientific calculation methodologies and the use of mild steel as a more stable building material. These characteristics make Müngsten Bridge a well-designed piece of engineering.

Due to these features, Müngsten Bridge can be considered as a successful combination of scientific, economic and aesthetic qualities. Its construction merges harmoniously with its environment, a fact which even allowed to adapt it to the requirements of the homeland protection movement ('Heimatschutz') at the time of its construction. As a result, Müngsten Bridge embodies a milestone with regard to both scientific-theoretic control of steel bridges on a large scale and their assembly technologies. At the same time, scientific calculation methodologies and both innovative construction materials and building technologies were introduced.

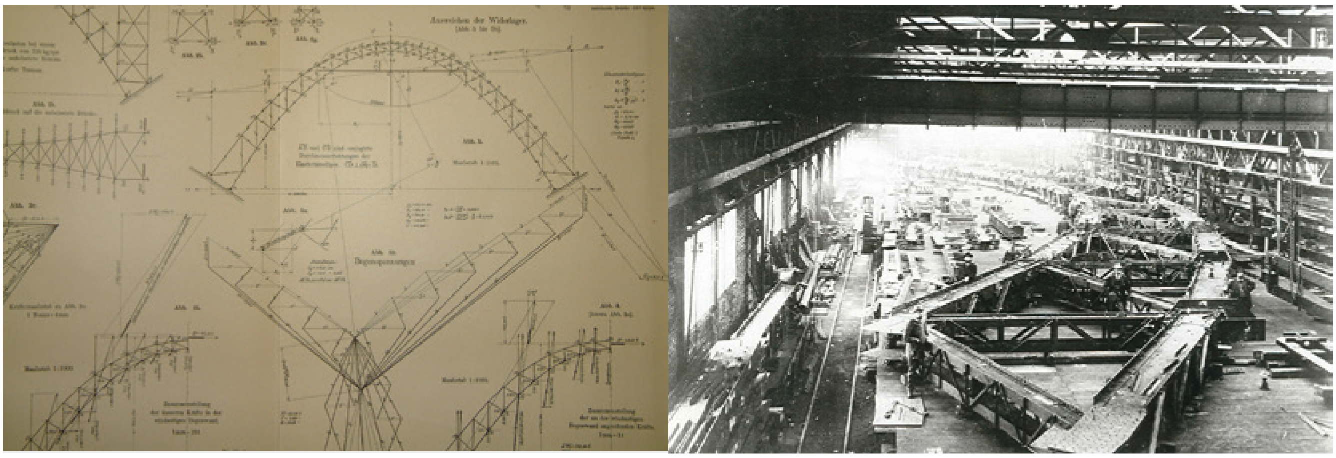

fig. 2: Müngsten Bridge under construction and drawings of the bridge construction (© Vereinigte Maschinenfabrik Augsburg und Maschinenbaugesellschaft Nürnberg, A.G, MAN Museum und Historisches Archiv)

fig. 3: Müngsten Bridge under construction and short before completion of the steel truss arch in 1897 (© Stadtarchiv Solingen, MAN Museum und Historisches Archiv)

3. Müngsten Bridge as a symbol of German state formation

The construction of Müngsten Bridge would not have been feasible without the know-how of bridge building technology of other European countries. The aforementioned truss arched bridges of the French company Eiffel were particularly important in this respect. The 'Garabit Viaduct', spanning the valley of the river Truyère in the Ardèche and built between 1879 and 1884 by Gustave Eiffel (1832-1923) and by his chief engineer Maurice Koechlin (1832-1946), shows the closest relation in terms of construction. The Garabit Viaduct followed two bridges erected earlier by Eiffel, the Ponte 'Maria Pia' (1875-1877) and 'Ponte Dom Luís I' by Theophil Seyrig (1886) which are crossing the river Duoro in Porto, Portugal.

It is very likely that Müngsten Bridge was consciously erected in concurrence to these bridges in other European countries, particularly France. Similar to the two bridges spanning the Kiel ship canal ('Nord-Ostsee Canal') at Hochdonn and Grünenthal it was conceived as a symbol of the technological and economic strength of the re-founded German Empire. Hence, the bridge should show the competitiveness of the industry in Germany shortly after its state formation in 1871. The then name 'Kaiser-Wilhelm-Bridge' emphasises these great ambitions.

fig. 4: Picture postcard of Müngsten Bridge showing a comparison of the bridge's size with other buildings, especially Cologne Cathedral which was finalised in 1880. Similar to Müngsten Bridge also Cologne Cathedral can be considered as a symbol of the German state formation. (© Stadtarchiv Solingen)

4. Müngsten Bridge as an identity-builder of the tri-city region of Solingen, Remscheid and Wuppertal ('Bergisches Städtedreieck')

Against this background, it is obvious that Müngsten Bridge played not only a significant role with regard to the technical building history of the Second Industrial Revolution. It was also a 'political icon' with a high symbolic value and attractiveness. Already during the building activities of Müngsten Bridge restaurants and even gazebos such as the 'Diederich-Temple' were erected, serving as facilities to streamline a large number of visitors and providing scenic views to the bridge within the valley of the river Wupper.

Due to its symbolic meaning, Müngsten Bridge became also a topic for culture and art. Numberless movies, photographs, paintings, poems, and songs illustrated Müngsten Bridge as a new technical achievement. The bridge was even associated with myths such as the legend that the truss arch was closed with the so-called 'Golden Rivet'. Besides its function to facilitate traffic in- and outside of the tri-city region of Solingen, Remscheid and Wuppertal ('Bergisches Städtedreieck') especially due to these elements the bridge became an important identity-builder in this region.

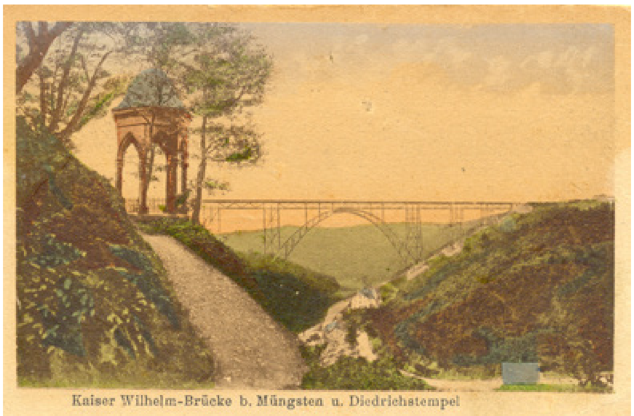

fig. 5: Picture postcards of Müngsten Bridge showing the so-called Diederich-Temple which was erected to provide a scenic view to the bridge and the former Restaurant 'Zur Bergischen Schweiz', meanwhile replaced by Haus Müngsten' (see fig. 6). (© Stadtarchiv Solingen)

5. Conclusion: A combined strategy of preservation, sustainable use, and awareness-raising to guarantee the future of Müngsten Bridge

Since its completion in the year 1897 Müngsten Bridge was used continuously. Greater maintenance works which took place in the 1930s, 1960s and in the recent years did not transform its original structure. Only in the year 2011, the bridge was closed, a fact which was caused by the tendency of brittleness of the bridge's construction material, mild steel. Meanwhile, the bridge has been opened again for regular train traffic and also in the future it is planned to use the bridge for local public transport. Railway companies have already been contracted to ensure its sustainable future use. Hence, it is already made sure that Müngsten Bridge will serve its original purpose also in the future.

The upkeep of the bridge is currently handled in close cooperation of the owner German Railway networks ('DB Netz AG'), the Regional Agency for Monumental Preservation in the Rhineland ('LVR-Amt für Denkmalpflege im Rheinland), as well as the Local Monuments Preservation Department of the Municipalities of Solingen and Remscheid. Thus, a stable network to safeguard the bridge has been created. Besides, it is planned to establish a friends' association with the goal to further support the upkeep of the bridge. As a result, the bridge will also enjoy the support of the citizenship of the three Municipalities Remscheid, Solingen and Wuppertal.

The bridge's tradition as an identity builder for the tri-city region of Solingen, Remscheid, and Wuppertal plays an important role to guarantee its future. A valuable element to prolong this tradition is the so-called 'Müngstener Brückenpark' (Müngsten Bridge Park). The park was realised in 2006 on basis of an international design competition and it was honoured with several awards. An important feature of the park is the so-called 'Brückenfest' ('Bridge Celebration') which is annually celebrated beneath the bridge. Besides, school classes in the region visit Müngsten Bridge and the Müngstener Brückenpark regularly. As a result, the Müngstener Brückenpark guarantees that the tradition of the bridge as an identity-builder for the tri-city region of Solingen, Remscheid, and Wuppertal stays alive. Hence, it supports both the bridge's significance within the valley of the river Wupper, nowadays a protected EU-Fauna Flora Habitat area, and the bridge's preservation.

fig. 6: Müngsten Bridge, Brückenpark Müngsten and Haus Müngsten' (© Stadt Solingen, Annette Nothnagel, Karl Adolf Tillmans)

The intended transnational nomination of Müngsten Bridge together with the two Portuguese bridges 'Ponte Maria Pia' and 'Ponte Dom Luís I', the 'Garabit Viaduct' in France and the 'Ponte San Michele' in Italy for the UNESCO World Heritage List is meant to support this combined strategy of preservation, sustainable use and awareness raising. Since the construction of the bridge is documented in an excellent manner it is also intended to stimulate research on the bridge's history. In this context, one idea is to open up these sources for education and capacity-building so as to build up additional know-how on an international level with regard to the history of bridge construction in Europe and the latest preservation strategies.

However, the symbolical role of Müngsten Bridge as an icon of national pride will be consciously changed by the intended transnational World Heritage nomination project. The future symbolical meaning of Müngsten Bridge will be not to mark borders between nation states, but rather to support intercultural exchange on a European and even worldwide level.

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SAN MICHELE BRIDGE – ITALY UNESCO WORLD HERITAGE LIST APPLICATION

Municipalities of Paderno d'Adda and Calusco d'Adda, Gianpaolo Villa (Assessor, Paderno d'Adda)

San Michele Bridge – Why the UNESCO World Heritage list application?

The Municipalities of Paderno d'Adda and Calusco d'Adda are pleased to submit the application for the inclusion of San Michele Bridge in the UNESCO World Heritage List in a transnational context.

The joint application with other 3 countries reinforces the Outstanding Universal Value and technological achievements that were the foundation of the mutual collaboration among European engineers and institutions in those difficult times – the 19th century – with local conflicts breaking out in different parts of the continent; those achievements were the effort to further develop commerce and communications, within regional and European levels

This application aims to preserve and renew the memory of a historical outstanding achievement for the boldness of its architecture and construction technique, state of the art design for the time, materials used, and the exceptional quality of the execution.

The Bridges are a testimony which has inherited from our ancestors who believed in the enterprise, boldly undertook it using ingenious equipment, inventing tools and instruments during its realization.

Nowadays, when static criticality and stresses to loads are easily identified through using technological tools, we cannot admire those who manually designed and tested the endurance of the bridge subject to the transit of heavy vehicles and exposed to the winds of the valley.

From a historical perspective, the San Michele bridge has brought many benefits to the whole territory as a link between the former Duchy of Milan and the Republic of Venice; territories once separated by the Adda river and united through the „Bridge" in its dual meaning: bridge in terms of rail / road link and bridge between different cultures and willingness to unite them.

The Municipalities of Paderno d'Adda and Calusco d'Adda share the noble aims of the founders of the United Nations Educational, Scientific and Cultural Organization (UNESCO) and the content of the UNESCO Convention, which supports and encourages the participation of local communities in the safeguarding of heritage sites of humanity.

We consider this application to present Outstanding Universal Value (OUV), especially being combined in a transnational context with other similar structures at the same typology, era and constructive technique, uniqueness, and irreplaceability, in which the following characteristics can be underlined:

» mastery of human creative genius
» testimony of a significant cultural, architectural and technological change
» state of the art for architectural construction

UNESCO's World Heritage is not only an honorary title but a warning to posterity that the bridge may always be kept in full efficiency and security, so as to be appreciated by anyone who travels by public or private means, by visitors, by students of engineering, architecture, and fine arts. It is an impulse to preserve the work for conscious tourism, following the cycling path at the Adda river level.

The structure, inserted in a wild but extraordinary environment, contributes to the appreciation of other man-made works that have contributed to the industrial development of Italy. In the same valley of the Adda, within a few hundred meters, we find dams and water channels to feed hydroelectric power plants of the early 1900s, derivative channels, the Naviglio of Paderno with its locks and basins, initially conceived by Leonardo da Vinci and eventually realized in 1777, religious buildings and recovered archaeological sites.

1. Historical and Economic Context of the Bridge area

The San Michele Bridge, between Paderno d’Adda and Calusco d’Adda, was built from 1887 to 1889 and represents a masterpiece of the iron technology of the time.

From a historical point of view, the importance of the San Michele bridge equals with the Eiffel Tower, as it was built in the same years and with the similar technology; both structures became symbols of industrial triumph in their countries. The San Michele bridge was the greatest single-arch bridge in the world, at the time of its construction, for what concerns dimensions and the fifth as regards the width of its span.

Being basically identical to the viaduct de Garabit, which was erected only four years before by Eiffel in Alvernia, this structure has an experimental character, as it was one of the first constructions to employ the theory of elasticity ellipse. Its total length is 266m and a central span of 150 m supports it with 7 iron pillars; it has a two-level deck with a railway and a street for vehicular traffic.

The bridge, located in the heart of the quadrilateral between the cities of Milan, Bergamo, Como and Lecco, where allowed stable and swift communication between two parts of Lombardy (formerly belonging to the Republic of Venice and the Dukedom of Milan), reducing times and establishing new trade routes between productive areas of Piedmont and the factories of the eastern part of Lombardy, namely around Brescia and Bergamo. Figure 1 represents the important location of the bridge on the map.

Milan was the polar star of the economy of the Dukedom and required goods and manufacts from its territories and from foreign countries, the Republic of Venice was being one of the most important of these states. From east to west, the connections were satisfied by the water canals (Martesana from Trezzo to Milan) or rivers (the river Po being the most important) in the 15th century. Another important way was the one from north to south, basically from lake Como to Milan which was opened building and a canal with locks and basins in 1777: Architect Meda finally realized the Naviglio di Paderno, that contributed to the efficient transport of goods coming from Northern Lombardy, Switzerland, and Germany through the alpine passes used for centuries for communication with Italy. This new canal boosted the economy through taking mostly iron, wood, stone as well as textiles toward Milan markets.

Also, the goods from the Bergamo area of the Republic of Venice were used the canal as well as loading boats near Lecco or at Trezzo to use the Martesana canal. Despite the political separation and occasional clashes, the two different territories grew together in a sort of symbiosis while maintaining some cultural and behavioural differences, which are still mildly present. However, after some decades, the water transport was not enough to carry all the necessary goods and the Railway explosion in the second half of the nineteenth century boosted economic activities everywhere. Moreover, the Adda river powered several textile factories which also increased in numbers and size due to the growing demand for silk and wool of the Milanese bourgeoisie.

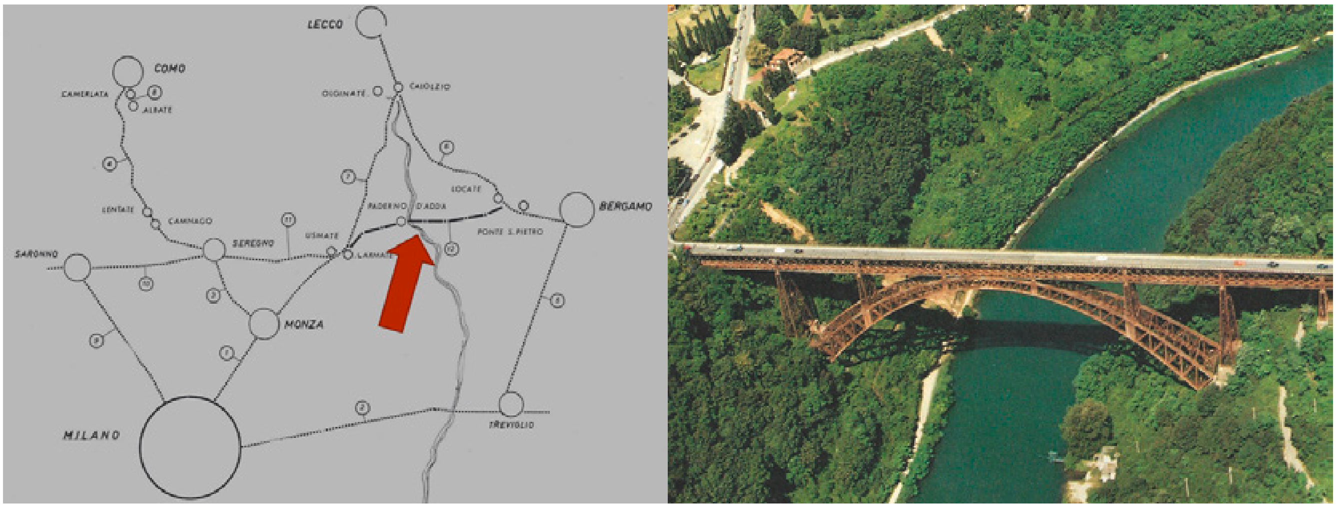


Fig. 1: (left) Map of Central Lombardia railways system and San Michele position (© from the book: “Il Viadotto di Paderno sull’Adda” – Habitat, Centro Iniziative Culturali, Paderno d’Adda, 1989) (right) The San Michele aerial view between Paderno and Calusco (© Osvaldo Villa)

In 1840, the first railway of Lombardy was realized between Milan and Monza and consequently, the others were planned and realized in following years. The connection between Como, Milan, and Bergamo was studied by the best engineers of the time and the Paderno area was deemed to be the best for a railway bridge connecting such the important areas of Lombardia. When the project started to consolidate, there was also pressure by the municipalities of the area for the enterprise to be undertaken, who wrote letters to the relevant authorities pushing for the project.

The transport of goods via railway affected the use of the Naviglio as a waterway; it was used until 1930 and was then decommissioned. This meant the end of some businesses in the areas, like small rest areas, animal stables, and even restaurants.

At the beginning of 20th century, big dams with hydroelectric production units were built in the area which are still operating today: they provided electric energy to Milan and helped the development of the industries that made the Lombardy and Milan areas as one of the richest zones in Europe. A characteristic Poiret dam (made with wood poles), which serves mainly as a regulator of the river floods and the derivatives flow control, is visible from the San Michele bridge.

All these manufacts, like dams and canals, are the parts of the industrial archeology of the Adda Valley, where the human work built an eco-system which helped to enhance the beauty of the natural canyon.

2. Adda River Valley – History, Communities, and Industrial Archeology

Parco Adda Nord

The San Michele bridge is a part of Parco Adda Nord, a regional park was created to protect the Adda river environment. The park territory is quite ample and its extension is 5,650 hectares, including municipalities of the provinces of Lecco, Bergamo and Milan: the maximum altitude is 260 m asl, while the minimum is 100 m.

The Adda river is considered the "cradle" of the Italian industrial revolution. The mills, water mills, derivation channels, thriving factories powered by the flow of waters were built along the river banks for centuries. Very common were the filande, silk mills, where silk yarns were spun and woven from silkworms bred in peasants' families, an activity that integrated their incomes, that in many cases became their main job. Textile factories were a major industrial activity in the Adda river area until a few decades ago, when production was delocalized to low-cost countries.

The river made a great contribution to the industrialization of Lombardy: the hydroelectric industry started at the end of 1800 with the construction of the power plants that would produce energy for the textile factories (including the one of the Crespi UNESCO Heritage site).

The major hydroelectric power plants are the "Bertini" of 1898, "Taccani" of 1906, "Esterle" of 1914 and "Semenza" of 1917, all currently are operational and architecturally representative landmarks that can be considered "cathedrals of energy", witnesses of an economic progress that respected the beauty of the natural environment.

However, the two most important monuments are the San Michele Bridge (1889), a hardy project that pairs with the Eiffel tower and the Crespi village (1878), an example of a company town which for this reason was added to the UNESCO World Heritage List in 1995.

The local history is not limited to the last centuries but goes back to at least the Roman empire. This river crossing was vital also at that time and several fortified camps were created to guard the crossing and to block enemies: 15 km north of Paderno there was a Roman bridge, part of the Como-Aquileia road, one of the most important east-west communication way of that time.

The river itself marked the boundary between the Duchy of Milan and the Republic of Venice and represented an important route of cultural and commercial communication to both Bergamo and Milan Charlemagne, Frederick II and the representatives of the Visconti family believed to have stopped in the area during military campaigns and journeys around Italy.

San Michele was built in an area where the morainic glaciers of the quaternary era, descending from the Alps to the flat land, has defined a breathtaking scenery. The deposits left by the glacier‘s movements, in the area of the bridge and down to Trezzo, are the so-called conglomerate counters (“ceppo”, i.e. rocky stump). Steep walls and falesiae are the characteristics of the valley, especially in the Calusco side, where is so famous for the climbing.

The valley has also covered with forests and woods with pines, locust trees, plane trees, poplars, willows, oak trees, alders, hornbeams, hazels. Also, humid area and ponds exist nearby with water flowers of several types, also attracting birds, amphibia, herons, and swans among others.

The history and culture of this part of the Adda river are also linked to the studies Leonardo da Vinci made while trying to design a navigation channel which would be able to overcome a difference in the level of 26 metres from Paderno d’Adda to Porto d’Adda, thus allowing communication between Como lake and Milan. Leonardo da Vinci also said to have used the beautiful scenery of the canyon as a background for the some of his famous paintings. The so-called Eco-museum Adda of Leonardo was decided to establish in appreciation and understanding of this famous painter and architect and his achievements.

3. Eco-museum Adda of Leonardo

The Eco-museum is a shared museum where all the exhibits are not in a single place but are spread over a territory, creating an itinerary which comprises manufacts, bridges, points of interest which show the history of the place and its heritage. The museum was equipped according to the Frenchman Hughes de Varine stated’s conception of a museum: he stated that the traditional goal of a museum is to save for posterity a way of living and the reasons that led to it.

The Eco-museum does not consist only in a building where items are collected and exhibited; it is rather an area comprising wildlife, manufacts, buildings and engineering landmarks which have been part or have created, the history of the region and of its people.

Walking in this area make the visitors as a part of the museum and they can touch the collaboration between the local industrious people and the generous water.

The idea of an Eco-museum originated from the Rotary Committee for the restoration of the Adda‘s locks, as a first highlighted Outstanding Universal Value of the places, has been promoting the recovery of this old waterway. With the support of the Lombardia Region, the proposal subsequently obtained the recognition of the European Union, within the framework of the TERRA programme, which included it in the project Canaux Historique – Voies d‘eau vivantes. In 2001, following an agreement between the Ministry of the Environment and Regione Lombardia, a first approval was given for the creation of the first nucleus of the new reality, the Museo Adda di Leonardo. The work began with the restoration of the buildings located near the Rocchetta (the Stallazzo that has become a refreshment point, as well as the ex-ECUs of the Conca delle Fontane and the Conca Grande, today information centres).

The inauguration of the Eco-museum took place in May 2004. In the initial phase, the new „exhibition Space“ included the area from the dam of Robbiate to the hydroelectric power station of Porto d‘Adda. Later, the route was extended to the north to Imbersago and south to Cassano d‘Adda, always bearing in mind the same leitmotif: the genius of Leonardo.

Leonardo lived for almost twenty years in close contact with this river, leaving in his writings and in the territory traces of his passage. Here he made some of his drawings, portraying elements of the area in some of his famous works, for example, the two versions of „The Virgin of the Rocks“: The Parisian one at the Louvre and the London one at the National Gallery.

Leonardo also lived for years at the Villa Melzi of Eril in Vaprio. Gerolamo Melzi, Count Palatine and captain of the Milanese militia; the count’s son Francesco became Leonardo’s dearest pupil, followed him until his death and inherited all the artistic and scientific drawings and manuscripts. On behalf of the Duke of Milan Ludovico Il Moro, Leonardo studied for a long time how to make the

Adda River navigable in the section of rapids between Paderno d'Adda and Porto d'Adda. He also achieved the technology of a ferry that, even today, joins the banks of Imbersago and Villa d'Adda, is exploiting only the power of the current.

The itinerary of the museum has developed a number of stops along the river where signs inform about landmarks, sites of interest or wildlife. The Eco-museum is organized in "rooms" and here below, some of them are evidenced.

Fig. 2: The San Michele and the "Semenza" hydroelectric plant (© http://addadileonardo.com/sale/ponte-san-michele/)

The San Michele bridge is part of the Eco-museum and is the 3rd "room" of this "exhibition". The fourth room is the inlet of the Naviglio of Paderno. It rises downstream of the bridge. A dam built with long wooden rods that bar the river giving origin to the Naviglio of Paderno. Further downstream is the tumultuous rapids of the river Adda.

Fig. 3: The inlet of the Naviglio of Paderno and Poiret Dam (© Vera Carusi)

4. The Railway and San Michele Bridge
Planning and Design

The railway and the bridge were studied by a special office of the Government that started working after the approval of the law of 29th July 1879, which initially defined the building of a railway of the so-called iii category. All the involved municipalities were informed of the decision in 1880. By 1885, the railroad was almost completely laid out, but the viaduct had not been started yet. The delay was caused by a disagreement between the Government and the involved provinces on the overall cost of the bridge and, more importantly, on the definition of the quota per each party.

In order to overcome this, the government tried to find a technology to build the bridge so that it would be less expensive than the one originally designed. Four projects were presented and the Società Nazionale delle Officine di Savigliano (Cuneo) claimed that they would be able to build the iron viaduct with the lowest cost and in a shorter time; therefore, they won the bid (the project was submitted on the 17th of March 1886) and only three years later the bridge was completed.

The project was drawn by a Jules Rothlisberger, technical director of the Officine di Savigliano. Jules Rothlisberger, a Swiss, was born in Neuchatel on 17th February 1851. He graduated in 1872 from Zurich University and specialized in projecting metal structures at the Studio in Berna. In 1884, he started working at Società Nazionale Officine di Savigliano as Technical Director. In order to precisely calculate the stability of the structure, Röthlisberger used rigorously the theory of elasticity ellipse, as stated by Culmann, his former teacher at Politecnico of Zurich, which was based on the proportion between stress and strain.

Fig. 4: Jules Rothlisberger (from the book "Paderno d'Adda, storie di acqua e di uomini; Habital Centro Iniziative Culturali, Paderno d'Adda 1989)

The design and calculations were not so easy and immediate. Even if some bridges had already been built in Europe, the project was quite challenging and Eng. Rothlisberger made a great job of it. The choice of a single-span bridge, without any mid-arches, was due both to the shape of the narrow steep gorge that had to be bridged and to the necessity of allowing the existing navigation along the river Adda.

The arches stand on concrete masonry piers built half way up the descending sides of the gorge. The cost was estimated at 1.850.000 lira for the construction, plus 128.717,50 for the preliminary work. The iron, imported from German foundries, was worked at Officine di Savigliano. The units for the building of the bridge were transported to Paderno by railway and set in position by means of a cableway powered by a powerful locomotive. work for the bridge started in 1887 with the building of a scaffolding service bridge, made using 1.800 m3 pine of Bavaria. The construction was completed in March 1889. A test was performed in May of the same year: it consisted in the passing of a train composed of three 83 tonnes locomotives and 30 carriages travelling at the 'high' speed of 45km per hour; the total length of the train was much longer than the whole length of the bridge and weighed 850 tonnes.

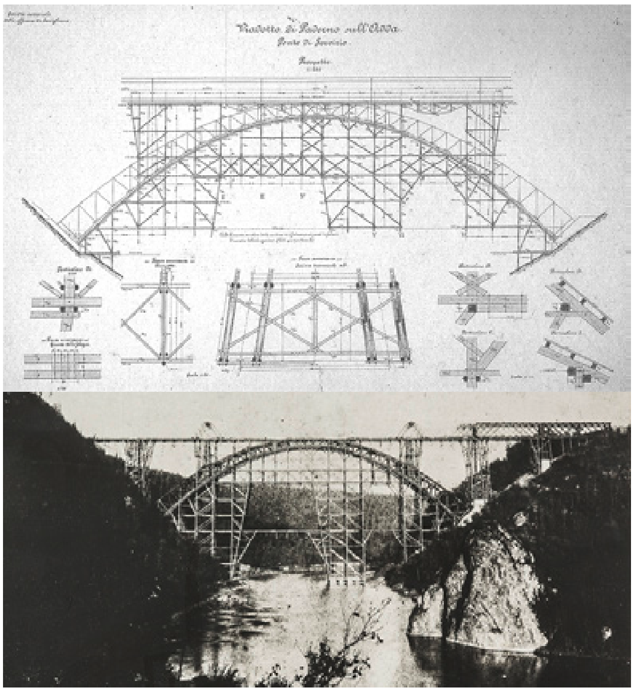


Fig. 5: (left) The service bridge components (drawing from the original design of the Bridge – Officine di Savigliano), (right) The service bridge with the arch structure completed (from the book: "Il Viadotto di Paderno sull'Adda" – Habitat, Centro Iniziative Culturali, Paderno d'Adda, 1989)

The preparation of the temporary structure took as long as 11 months because of the steepness and difficult terrain of the banks; in the meantime, plinths and foundations were being built using stone and granite which were transported along the river Adda on barges.

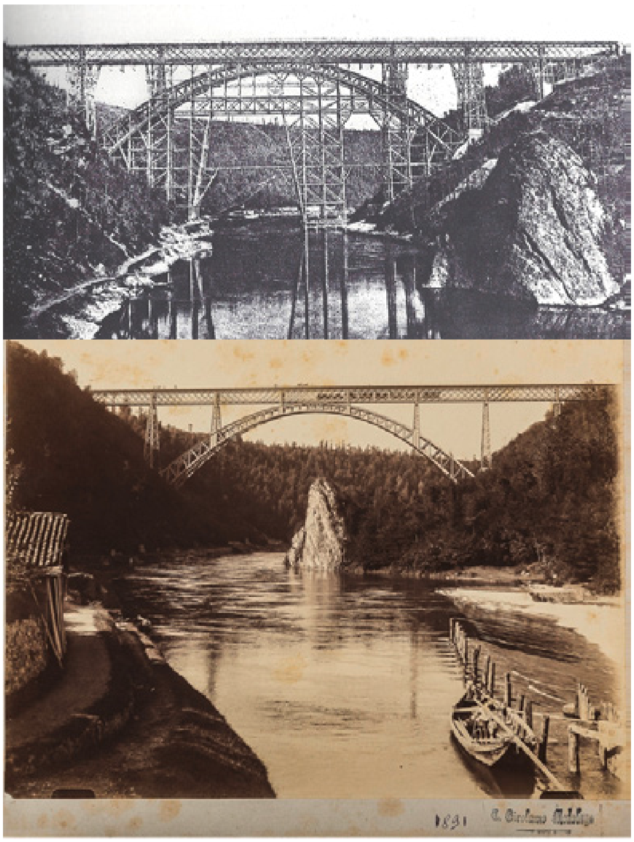


Fig. 6: The San Michele Bridge almost completed (from the book: "Il Viadotto di Paderno sull'Adda "– Habitat, Centro Iniziative Culturali, Paderno d'Adda, 1989),
The San Michele Bridge in operation, with transit train – 1891
(© Girolamo Medolago)

The Officine Nazionali of Saviglano succeeded in promoting their achievement by publishing in the leading (and maybe only one) tourism magazine, "Rivista Mensile del Touring Club Italiano "a styled picture of the Bridge.

Fig. 7: The cover of the September/October 1889 issue of the Touring Club monthly magazine with the San Michele Bridge

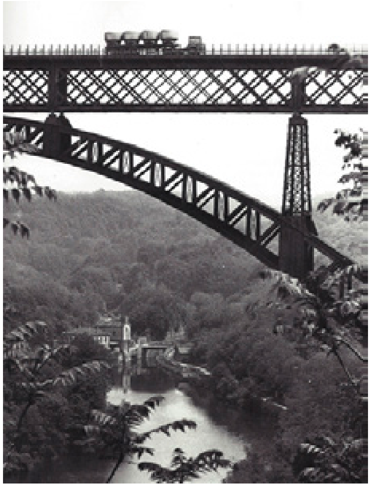
Even if the reason for the choice of the iron technology was economical, it turned into a winning long-term success, due to its robustness and beauty. This shows that an economical choice does not always turn out to be a poor in quality or even ugly: state of the art technology with hidden sophistication but with pure and linear design, always represents a winning factor in the progress of humanity.

The iron Bridge in Paderno is the major Italian monument of the iron architecture of the 19th century and represents a fundamental landmark in the history of Construction Science. It was declared National Monument in 1980 and under protection by the Ministry of Culture (Department of Archeology, Fine Arts, and Landscape.

The goal of this UNESCO nomination to the World Heritage List is also to uncover such genial achievement by humans, who, in spite of all the difficulties of that time, managed to achieve a goal difficult to imagine and close to be lost. The reasons that link humans together are always more numerous than those that separate them. State of the Art technology, brilliant men, and spectacular environment blended together the admiration of posterity in the past 130 years. It depends on the new generations to safeguard and continue the way which inherited from past for next generation.

5. Scenic views of the San Michele Bridge

Fig. 8: (© Arch. Filippo Alberganti – ENEL Group)



(Picture from the book: "Il Viadotto di Paderno sull'Adda" – Habitat, Centro Iniziative Culturali, Paderno d'Adda, 1989)

Fig. 9: (left) (© Pino Sbarra) (right) (© Fabio Ripamonti)

6. Technical Data of San Michele Bridge

LINEAR DECK

» Total length 266 m

» Height 6 m

» Width 5 m

PARABOLIC SPAN

» Central span 151 m

» Arrow height 37 m

HEIGHT OF THE ROAD DECK

» From the normal level of water 80 m

MATERIAL USED

» Stone of Moltrasio 5.000 m3

» Granite of Baveno 1.200 m3

» Iron 2.625 tonnes (from German foundries)

» Pine of Bavaria 1.800 m3

» 100.000 rivets

EXECUTION TIME

» January 1887 – May 1889

TOTAL COST

» 1.978.717,50 Lire

USE OF THE BRIDGE

» Railway and Vehicular transit

OWNER

» Rete Ferroviaria Italiana (RFI)

7. Centennial Celebration in 1989

In 1989, the municipalities of Paderno d'Adda and Calusco d'Adda celebrated the centennial of the San Michele. Several events were organized, in different areas, including an Air Show by an acrobatic display team, the National Band of Carabinieri on Horses; among the cultural events with the participation of several Italian Ministers and Members of Parliament were a conference on the bridge, a press conferences in Terrazza Martini in Milan and a concourse with selection of best drawing/painting representing the bridge, with a panel composed of major Italians designers. The winning drawing is printed below:

Several thousand people attended the various events, with a participation never seen before, a celebration that is still remembered as the bigger event of this part of Lombardy, another sign that the San Michele is an icon of our territory, waiting for the definitive "consacrazione" of the UNESCO World Heritage List.

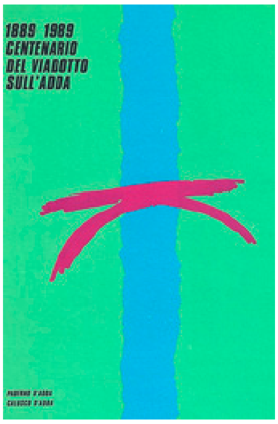


Fig. 10: The winning drawing of the centennial concourse (© Municipalities of Paderno d'Adda and Calusco d'Adda)

This event was also the illumination of the bridge, that for some years after the centennial, attracted people from everywhere. It was also realized by local citizens with the help of sponsors. Some of them are ready to illuminate the bridge again after the renovation works which is using the most updated and reliable technology.

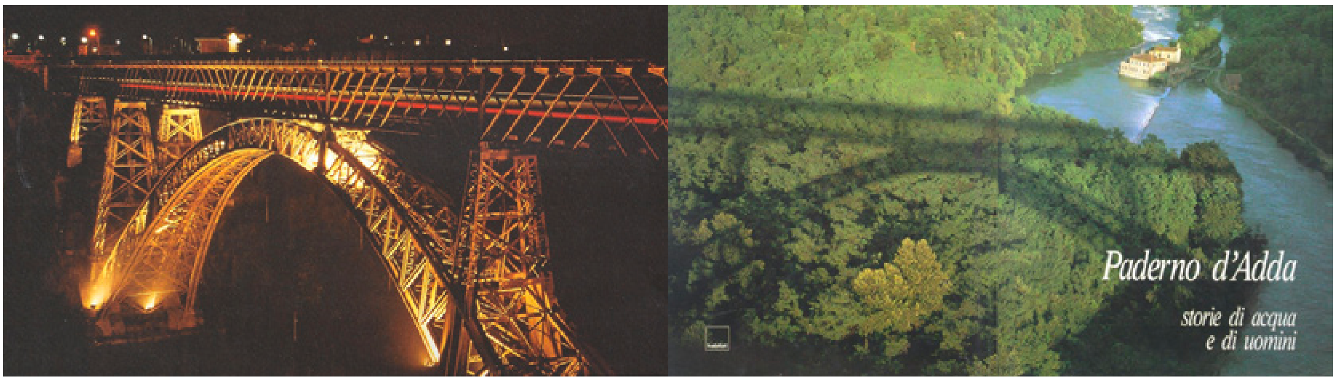


Fig. 11: (left) The illuminated bridge (© Fabio Ripamonti) (right) Cover of the book "Paderno d'Adda, storie di acqua e di uomini; Habital Centro Iniziative Culturali, Paderno d'Adda 1989 (© Piciotti Ernesto)

Consequently, the exhibition held in 2017, to celebrate 130 years from the beginning of the works. This exhibition consisted of 32 panels describing the history of San Michele bridge

Fig. 12: The exhibition manifesto to celebrate 130 years from the beginning of the works for the bridge (© courtesy of Pro Loco of Paderno d'Adda, Pro Loco of Cornate d'Adda, Vittorio Alberganti).

8. Maintenance and Consolidation of the San Michele

Major maintenance and consolidation works are planned for the year 2018; the work will be undertaken by RFI Rete Ferroviaria Italiana. The last major maintenance work was undertaken in 1954; after that, the railway line was considered a minor one and no investment were planned to maintain the bridge at its best.

The structure is not in good condition and there are traffic restrictions:

» Maximum train speed: 15km/h
» Train length reduced with respect to standard Regional Services
» Road alternate one-way sense of direction with limits
» Pedestrian sidewalks unfit for use at the moment
» Technical problems – due to the age of the bridge
  » Corrosion
  » Water stagnation
  » Warpage
  » Damaged rivets and bolts
  » Highly uneven road surface

Some years ago, the idea that this line could still play a role in the Lombardy transport network gained support and the RFI decided to invest on the renovation. Maintenance and restoration of the bridge consist in restoring the original bridge conditions with structural improvement work to reach a nominal life of 50 years (until 2070).

This, by doing:

» Surface cleaning
» Replacement of damaged draw pieces
» Local reinforcement and plating
» Rod sealing
» Reconstruction of pedestrian sidewalks
» Surface protection
» Reconstruction of asphalting

The goal is also to achieve a train speed of 70 km/h. The project is under the supervision of the Mistry of Culture (Department of Archeology, Fine Arts and Landscape) involved in both executive design and execution verification. The estimated cost is 21.6 million euro (20 mio iron structure funded by RFI; 1,6 mio the road on upper deck funded by Regione Lombardia). As the works will be done with the aim of maintaining the train service as regular as possible and avoiding traffic block, the restoration time is estimated at about 36 months.

References

The information and pictures included in this document are taken from some books written in the past to celebrate the centennial of the San Michele bridge or a few years after.

Several other books talk and elaborate the various aspects of technology, history, economy etc. and are listed inside the mentioned books, as the authors looked to endless sources, listing all of them in an ample bibliography.

As the main source has been considered the books:

- *Il Viadotto di Paderno sull'Adda 1889 – 1989, edited by "Habitat, Centro di Iniziative Culturali ", Paderno d'Adda, 1989*

  The book has been conceived and edited to celebrate the San Michele bridge, with contribution from scholars who studied the area and the bridge in particular.

  Tables, charts, drawings and some pictures are from this book (some are from the 1889 book, "il Viadotto di Paderno sull'Adda" edited by Officine di Savigliano

- *Calusco d'Adda, edited by Gabriele Medolago, Calusco d'Adda 2007*
- *Paderno D'Adda, storie di acqua e di uomini, edited by "Habitat, Centro di Iniziative Culturali", Paderno d'Adda, 1989*
- *Restauro Magazine #73-74/1984 "Il Ponte di Paderno: storia e struttura! By V.Nascè, A.M.Zorgno, C. Bertolini, V.I. Carbone, G. Pistone, R. Roccati – Edizioni Scientifiche Italiane, Napoli 1984.*

Inside the above mentioned books, there is an ample Bibliography

Parco Adda Nord: http://www.parcoaddanord.it/

Ecomuseo Adda di Leonardo: http://addadileonardo.com/

Tourism resources: http://visitadda.com/
http://visitbergamo.net
http://www.valleadda.com/index.php

Calusco d'Adda: http://www.comune.caluscodadda.bg.it/

Paderno d'Adda: http://www.comune.padernodadda.lc.it/

Church of San Michele dei Verghi history: http://digilander.libero.it/caluscoarte/verghi.htm

Several pictures of the bridge: http://mapio.net/pic/p-58988544/

FIRST WORLD HERITAGE CONGRESS DOCUMENTATION – POINT OF VIEW FROM FRANCE

Karine Decq

At the time it was built, Garabit Viaduct was the highest viaduct in the world. It is a masterpiece of civil engineering and embodies the state-of-the-art technical and industrial development achieved at the end of the 19th century.

There is no doubt that it was a significant development of its period and that it now represents an industrial heritage that must be protected. Garabit Viaduct is emblematic both of the local area and the wider surrounding region. For the two communes of Ruynes-en-Margeride and Val d'Arcomie where it is located, and the Community of Communes of Saint-Flour, the preservation and development of this site are of key importance.

The local elected representatives and the community in which it is situated are all immensely honoured that it has been nominated at the 1st International Congress on "UNESCO World Heritage Bridges".

The expert guidance provided by the representatives of UNESCO, ICOMOS, and TICCIH, along with the talks by acclaimed experts on a wide range of subjects, provided a strong foundation for the project and suggests a very promising future.

The five metal arch bridges that have been selected across Europe have strong technical similarities, while all display their own uniqueness. They were all built at a very similar period of industrial growth. There is, therefore, a coherence that each bridge and each community can identify with.

We would like to thank the German authorities for organizing this congress. We are delighted to be welcomed as part of this project and are extremely grateful for the work and effort of all the people involved. To launch this project, the strategic planning committee has successfully liaised with an experienced team of people and has also secured the support of the German railway company, the Deutsche Bahn.

We learned a great deal throughout the course of the Congress and we now have a better understanding of what is involved in this process.

At the end of the Congress, the "Memorandum of Understanding" agreed by the towns involved, articulates a clear intention to work together and defines the numerous stages that are yet to be completed.

This European project for the joint serial transnational nomination of five grand-scale arch bridges for the UNESCO World Heritage List is highly motivating. The valuable links and rich exchanges underlying this project reflect the spirit behind the construction of the bridges themselves.

This nomination is also in perfect keeping with the work embarked on by local elected representatives of the Community of Communes of Saint Flour in 2017, to protect the natural environment of the Gorges of the River Truyère, which includes the site of Garabit Viaduct.

This first Congress has created the ideal conditions for a close partnership involving representatives of Garabit Viaduct and its community.

CHAPTER 5:

CONCLUSION

OUTPUT OF THE CONGRESS AND FUTURE PERSPECTIVES FOR THE PLANNED TRANSNATIONAL NOMINATION

Michael Kloos

The Congress "Bridges in the World Heritage", organised on the occasion of the 120th anniversary of Müngsten Bridge by the three cities Solingen, Remscheid and Wuppertal, aimed to develop a broader understanding of bridges in the World Heritage List. The second target was to determine which bridges are to be included in the UNESCO World Heritage List and to assess the chances to nominate jointly the bridges "Maria Pia" and "Dom Luis I" in Portugal, the "Viaduc du Garabit" in France, the "Ponte San Michele" bridge in Italy and "Müngsten Bridge" in Germany as a serial transnational World Heritage property.

The Congress covered three relevant topics related to the intended serial nomination proposal of the five bridges.

a.) The first part of the Congress dealt with the investigation and systematics of various types of bridges and their current representation in the UNESCO World Heritage List. At the same time, it was discussed whether and how the Thematic Study "Context for World Heritage Bridges" published by TICCIH and ICOMOS in 1996, should be supplemented and updated.

b.) During the second part of the conference, the five arch bridges on a grand scale were presented and future steps with regard to a potential nomination for the UNESCO World Heritage List were discussed.

c.) Besides this, it was a general aim of the Congress to deepen the connections between the owners, the countries and cities near these bridges and to exchange experiences with stakeholders involved in their conservation and restoration. During the Congress, the cities' municipalities involved in the nomination process – Porto, Paderno d'Adda, Calusco d'Adda, Ruynes-en-Margeride, Solingen, Remscheid, and Wuppertal – signed a Memorandum of Understanding. This document is meant to serve as a basis for the future nomination process on the local level of the various included municipalities.

In general, the meeting was the first opportunity for scientists, experts and politicians to exchange and broaden their know-how with regard to the transnational serial nomination proposal. Hence, it served as a vehicle to create both the scientific and the political background for the future nomination process.

1. The future transnational Serial Nomination Process for the World Heritage List

With regard to the future activities, it is important to consider that nomination proposal of UNESCO World properties has to integrate stakeholders on various levels:

a.) The member states of the World Heritage Convention, the so-called States Parties, are in charge to submit nomination proposals. To provide an overview about their planned nomination proposals, the States Parties are preparing Tentative Lists. States Parties have also to ensure the preservation of World Heritage Sites on their territory in co-operation with the involved municipalities.

b.) The Advisory Bodies of the World Heritage Committee, ICOMOS, ICCROM and IUCN, evaluate nomination proposals and monitor the state of conservation in World Heritage properties. ICOMOS, the International Council of Monuments and Sites, is in charge to provide these activities for cultural World Heritage properties. ICOMOS also evaluates and advises the World Heritage Committee concerning nomination proposals.

c.) The World Heritage Committee, consisting of 21 representatives of the States Parties of the World Heritage Convention, decides about the inscription of World Heritage properties into the UNESCO World Heritage List. The World Heritage Centre with its seat in Paris is supporting the World Heritage Committee.

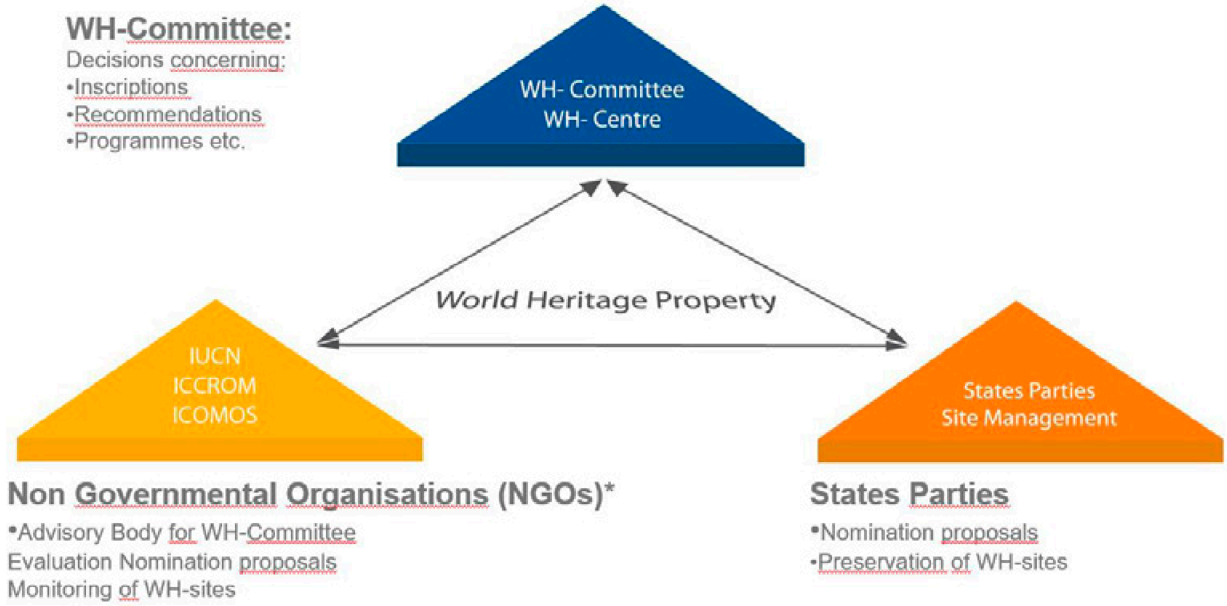


Fig. 1: Integration of the stakeholders on various levels for nomination proposal of UNESCO World properties (© Michael Kloos)

Against this background, it was a very valuable element of the Congress that attempts to tackle some of the main issues that will face the partners of the proposed serial nomination of European grand-scale arch bridges in each of their four countries could be illustrated based on experiences of the Forth Bridge / UK. The presentation about the Forth Bridge's nomination process illustrated clearly that a wide range of topics has to be covered during World Heritage nomination processes. This includes:

» making sure that each State Party is fully committed to the nomination process,
» getting onto the Tentative Lists in each country,
» ensuring adequate statutory protection is in place on both national and municipal level,
» forming partnerships with key stakeholders,
» winning the support of not only the owners but also the adjacent communities,
» bringing the condition of the monument up to standard,
» engaging with both the national and international branches of ICOMOS,
» managing the setting of the potential World Heritage bridges and associated potential buffer zones,
» and compiling the best possible records from the historic archive and new survey so as to provide a scientific basis for the future nomination process.

All these steps are necessary to make sure that there is sufficient scientific expertise to compile a convincing Nomination Dossier which has to justify the Outstanding Universal Value (OUV), Authenticity and Integrity ("inviolability") of the transnational series of arch bridges. To justify the OUV, the Nomination Dossier has to contain an international comparison and it also has to include a Management Plan, covering both the national and the international coordination of all activities with regard to the potential serial and transnational World Heritage property. With regard to the management of the five arch bridges, the example of the Forth Bridge / UK illustrates clearly that it will be particularly necessary to prove that the bridges can be preserved for future generations. Therefore, sustainable use of the bridges is an important element of such a management and preservation system

2. The future transnational serial nomination process

To tackle these tasks, it is obvious that all above-mentioned relevant stakeholders have to be involved from the beginning on in the nomination process. The planned second Congress in Porto on 21st-23rd June 2018 is an important second step towards these goals. Here, it is planned that the Municipalities of Vila Nova de Gaia / Portugal and Saint Flour / France will join the Memorandum of Understanding signed by the other involved municipalities during the first Congress in Solingen.

Besides the municipalities, the bridge's owners are very important stakeholders with regard to World Heritage nomination process. Hence, it is planned to sign a second Memorandum of Understanding during this Congress in which the various owners of the bridges express their support for the future preservation and sustainable use of the bridges.

Once all stakeholders on local levels are on board, it will also be necessary that all involved State Parties commit themselves officially to the serial transnational nomination process.

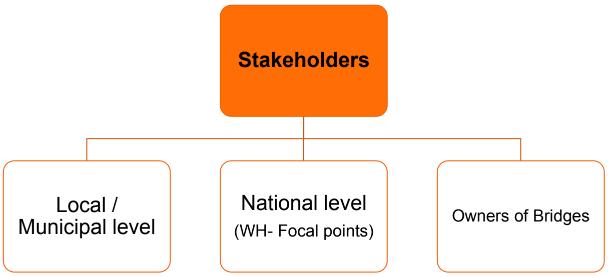


Fig. 2: The relevant stakeholders in different levels (© Baharak Seyedashrafi / Michael Kloos)

A second topic of the next Congress hosted by the Municipality of Porto will be to discuss the impact of the five bridges on the urbanisation and sustainable use of the five Arch Bridges. Besides, the future sustainable use of the bridges will be investigated so as to set-up the structure for their preservation in the future. In this context, international experts will exchange their experiences concerning conservation and restoration of the bridges. Thus, this Congress will provide an important perspective for future management of the five bridges. It can, therefore, be considered as a second milestone of the planned nomination process.

3. A roadmap for the future Transnational Serial Nomination Process for the World Heritage List

A third milestone of the nomination project will be to identify and recognise the potential Outstanding Universal Value (OUV) of the World Heritage Bridges. Accordingly, the authenticity and integrity of the five proposed World Heritage bridges must be outlined.

Consequently, a Nomination Dossier including the Management Plan for both the entire serial nomination proposal as well as separately for each bridge has to be compiled. To streamline these activities on an international level each of the involved municipalities should appoint representatives who can coordinate these activities on the local and national level.

It is obvious that these activities will require substantial financial resources, especially for the preparation of both the serial Nomination Dossier and the Management Plan(s). However, as a major benefit of these efforts the transnational serial nomination project of the five arched bridges will bring the involved nations closer together. In the future, the five arch bridges could serve not only as elements to bridge rivers and valleys. They could also contribute to exchange and to build up know-how beyond national boundaries and encourage a more global collaboration and cooperation towards the international protection of cultural heritage.

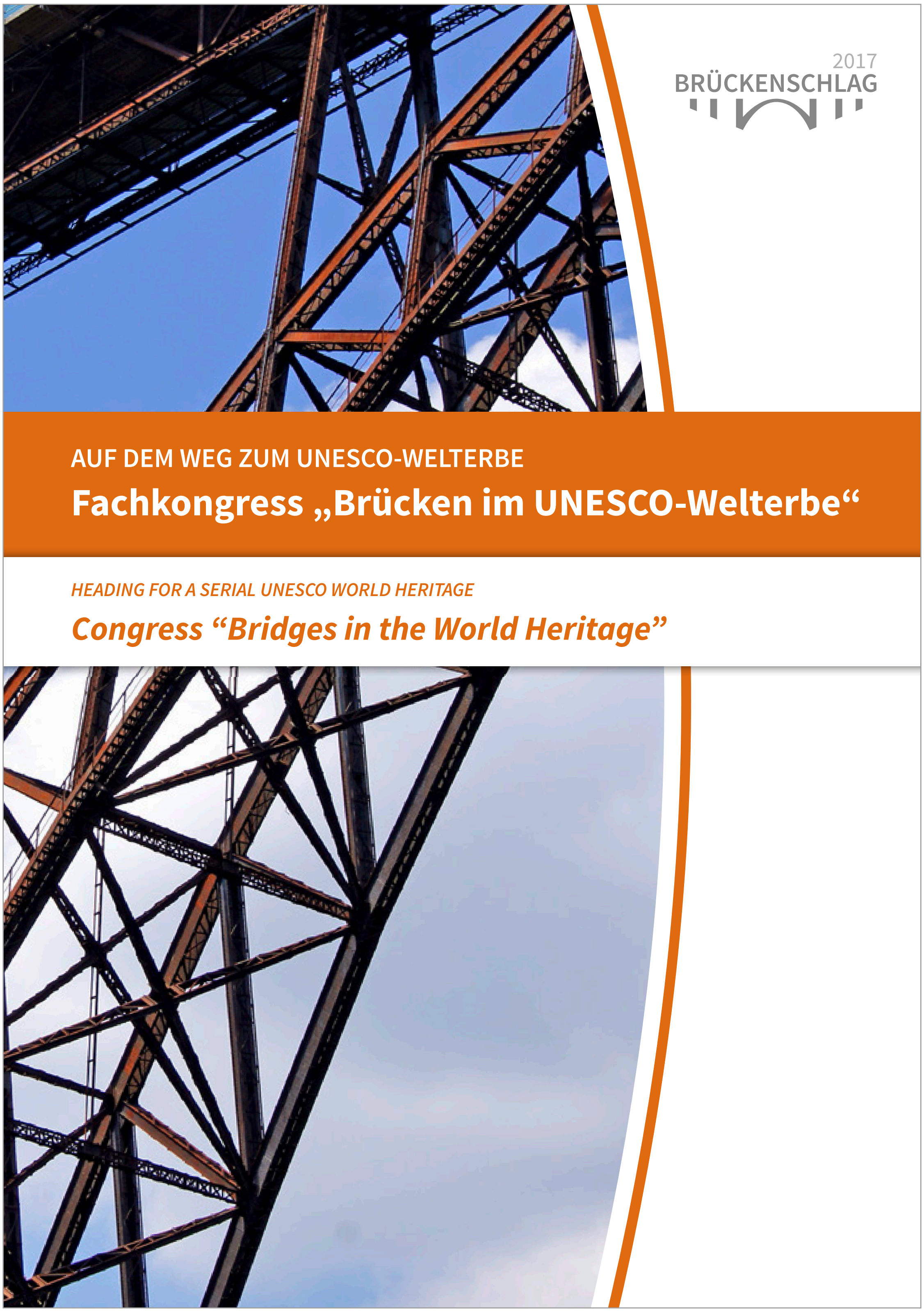
This is exactly what the UNESCO Report on serial nominations and properties WHC-10/34.COM/9B Paris, 31 May 2010 requires. Here, it is stated that "the concept of transnational serial nominations as a tool for international cooperation," should serve "shared approaches and thus better management and conservation practice."

	Date	Meetings and Outcomes	Follow-up Activities
Milestone 1: Overview of potential WH-bridges	2017	*Meeting in Solingen:* - Thematic report updated (basis) - Overview of potential WH-bridges **Outcomes:** **- Documentation 1: Publication of the first congress** **- Memorandum of Understanding 1**	- Municipality of the Porto clarifies the support and cooperation with Municipality of Vila Nova de Gaia and Saint Flour - All the municipalities should identify owners of the bridges and relevant stakeholders - All the municipalities should contact the owners of the bridges and inform about WH nomination plans - All municipalities should define a representative in charge of the WH-nomination - The owners, as well as, experts should be invited to the next meeting until May. 2018 **Goal: Set-up of organisational network for the nomination process**
Milestone 2: Overview of Urbanisation and Sustainable Use of potential WH-bridges	2018	*Meeting in Porto:* - Representing the publication of the first congress - Experts and owners report on future sustainable use of the bridges **Outcomes:** **- Documentation 2: Urbanisation and Sustainable Use for Bow Arch WH-Bridges** **- Memorandum of Understanding of the Owners of Bow Arch Bridges**	- Update Memorandum of the understanding; inclusion of the owners and Municipality of Vila Nova de Gaia and Saint Flour **Goal: Set-up standards and stakeholders structure for future management of serial nomination**
Milestone 3: Overview of potential Outstanding Universal Value of WH-bridges	2020 -21	- Representing the documentation 2 - Inclusion on Portuguese Tentative List - Clarifying the financing of Nomination Dossier and Management Plan **Outcome:** **Memorandum of Understanding of State Parties**	- Clarification of financial proposal for the serial nomination **Goal: Set-up of structure as well as financing for Nomination Dossier and the Management Plan**
Milestone 4: Compilation of Nomination Dossier and Management Plan	...	- Preparation of Nomination Dossier - Preparation of Management Plan: it is necessary to prepare a Management Plan for each bridge as well as entire serial nomination proposal	**Goal: Documentation of the Nomination Dossier and Management Plan**

Fig. 3: Working plan chart represents the process for the serial transnational nomination proposal "Grand-scale Arch Bridges from the 19th Century" (© Baharak Seyedashrafi / Michael Kloos)

APPENDIX

First Congress Program



2017
BRÜCKENSCHLAG

AUF DEM WEG ZUM UNESCO-WELTERBE

Fachkongress „Brücken im UNESCO-Welterbe“

HEADING FOR A SERIAL UNESCO WORLD HERITAGE

Congress “Bridges in the World Heritage”

First Congress Program

PROGRAM

Evening events 27 October 2017 Presentation: Prof. Dr.-Ing. Michael Kloos

18:00 - 19:00 pm Reception with drinks and finger food

18:30 - 19:00 pm Choir ‘Conbrio’ with international songs

19:00 - 19:05 pm Introduction
Prof. Dr.-Ing. Michael Kloos

19:05 - 19:15 pm Welcoming
Tim Kurzbach, Lord Mayor of Solingen

19:15 - 19:45 pm Lecture
“The Unesco Convention for the Protection of Cultural and Natural Heritage: Program and Perspective”
Dr. Birgitta Ringbeck (Departement of foreign affairs, Coordination Office World Heritage, Federal Republic of Germany)

The bridges – discussion on the podium

19:45 - 20:15 pm Presentation: Prof. Dr.-Ing. Michael Kloos
Participants:
» Dr. Birgitta Ringbeck (Departement of foreign affairs, liaison office world heritage)
» Dr. Miles Oglethorpe (expert on world heritage and bridges)
» Norbert Tempel (TICCIH Germany)
» Ass. Prof. Dr. Dr. h.c. mult. Christoph Machat (ICOMOS Germany)
» Carsten Zimmermann (department head strategic planning, city of Solingen)

20:15 - 20:45 pm Presentation: Prof. Dr.-Ing. Michael Kloos
Participants:
» Lord Mayor Tim Kurzbach (Solingen)
» Lord Mayor Burkhard Mast-Weisz (Remscheid)
» Deputy mayor Matthias Nocke (Wuppertal)
» Vice-Mayor Rui Loza (Vice-Mayor of the City of Porto, Portugal)
» Mayor Gérard Delpy (Mayor of Ruynes en Margeride, France)
» Mayor Renzo Rotta (Mayor of the city of Paderno d‘Adda, Italy)
» Representative from Calusco d´Adda / Italien
» Werner Lübberink (Corporate Representative of Deutsche Bahn AG Nordrhein-Westfalen, Germany)

with signing Memorandum of Understanding

20:45 - 21:00 pm 1st great Wupper Illumination-Staging

21:00 - 22:20 pm Buffet | Music Duo Brigitt’ Annessy, France / Music Trio Tres, Portugal

21:40 - 21:50 pm 2nd great Wupper Illumination-staging

22:20 - 22:30 pm 3rd great Wupper Illumination-Staging

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First Congress Program

World Heritage Congress 27 and 28 October 2017

Day 1	Presentation: Axel Föhl, Düsseldorf
11:00 - 11:15 am	Welcome Mayor Tim Kurzbach, Solingen
11:15 - 11:30 am	ICOMOS Germany statement Ass. Prof. Dr. Dr. h.c. mult. Christoph Machat, Köln
11:30 - 11:45 am	TICCIH Germany statement Norbert Tempel, Dortmund
11:45 am - 12:30 pm	Categories of bridges Prof. Burkhard Pahl, Leipzig
12:30 - 14:00 pm	Lunch break
14:00 - 15:00 pm	The Thematic Report by TICCIH: World Heritage Bridges Rolf Höhmann, Darmstadt
15:00 - 15:30 pm	Coffee break
15:30 - 16:15 pm	Bridges in the World Heritage: Nominations, Tentative Lists, Necessary add-ons? Rolf Höhmann, Darmstadt
18:30 pm	Evening reception Mayors of the cities of Solingen, Remscheid and Wuppertal

Day 2	Presentation: Rolf Höhmann, Darmstadt
09:30 - 10:00 am	Bridges in the World Heritage: Cantilever bridges – The Forth Bridge Dr. Miles Oglethorpe and Mark Watson, Historic Scotland
10:00 - 11:00 am	Bow arch bridges 1 + 2: Maria Pia and Ponte Dom Luis Prof. Dr. António Adão da Fonseca, Porto
11:00 - 11:30 am	Coffee break
11:30 am - 12:00 pm	Eiffel twin bridges: Maria Pia and Garabit viaducts Prof. Bertrand Lemoine, Paris
12:00 - 12:30 pm	The San Michele bridge (1889): historic background, recent assessment and monitoring, future perspectives Ass. Prof. Dr. Antonella Elide Saisi, Milano
12:30 - 13:00 pm	The truss arch bridge of Müngsten in the context of the 19th century bridge engineering Prof. Dr. Martin Trautz, Aachen
13:00 - 14:00 pm	Lunch break
14:00 - 14:45 pm	Round-table discussion – the large bow arch bridges as World Heritage?
14:45 - 15:00 pm	Final conclusions

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First Congress Program

WIR DANKEN UNSEREN SPONSOREN!

Stadt-Sparkasse Solingen

Stadtsparkasse Wuppertal

STADTWERKE SOLINGEN

WSW

Wenn's um Geld geht
Stadtsparkasse Remscheid

Stadtwerke Remscheid
Einfach mobil.

SILAG Handel
AKTIENGESELLSCHAFT

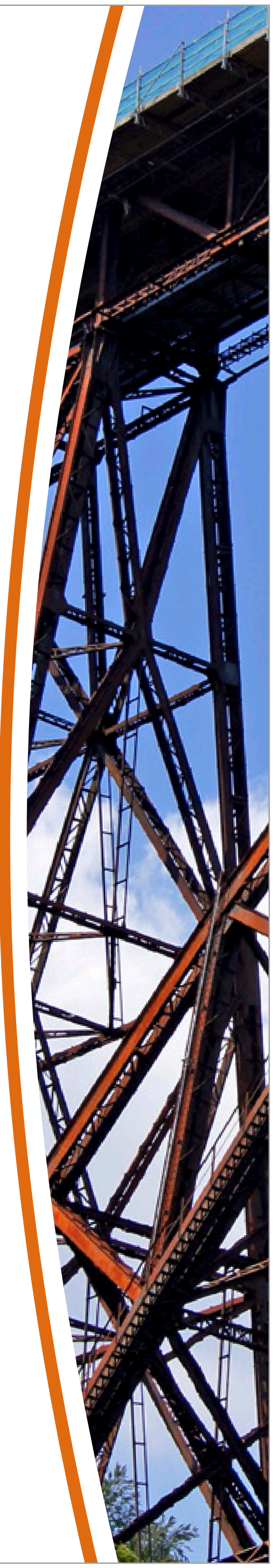
plan 8
Group GmbH

AWG

STAHLKREBS
Edelstähle seit 1882

FOURTEXX
HUMAN RESOURCE MANAGEMENT
BERATUNG · SOFTWARE · SERVICE

ST Solinger Tageblatt
...die Nr. 1 der Solinger



SPEAKERS AND AUTHORS

Decq, Karine

- » A graduated of the Management school of Clermont-Ferrand, Master degree of Business and administration, Master degree in tourism Clermont-Ferrand University, Engineer from the National school agronomic of Dijon (ENESAD).
- » A professional career in tourism and local area development.
- » Eight years of professional experience in the Alps in Savoie like Manager of tourism in mountain resorts in High Maurienne Vanoise and Maurienne.
- » Since July 2010, Director of the tourist office of the region of Saint-Flour in Auvergne.
- » The tourist Office composed of 53 communes around Saint-Flour, the main city.

Föhl, Axel

- » Axel Föhl, born 1947 in Coburg, Germany.
- » From 1974 to 2012 scientific researcher for the Industrial Heritage at the German State Office for Historic Monuments of the Rhineland.
- » From 1991 to 2009 speaker of the all-German Working Group of the State Offices for Preservation “Preservation of Industrial Monuments”.
- » 1992 – 2005 lecturer at Brunswick University of Technology: History of the Industrial Architecture, Conservation of Industrial Monuments.
- » 2005 – 2010 same function in Delft University of Technology.
- » Since 2009 Lecturer at Donau University Krems, Centre for Architectural-Cultural Heritage.
- » Since 1998 member of the Editorial Board of “Industrial Archaeology Review” and since 2013 member of the Scientific Committee of “Cuaderno de Notas.
- » Publication on Issues of Theory and History of Architecture”, Universidad Politécnica de Madrid.
- » Since 2010 consultative work in the framework of the UNESCO World Heritage, industrial sites in Switzerland, Norway, the Netherlands and Germany.

Prof. Dr. da Fonseca, António Adão

- » Civil engineer since 1971,
- » Consultant and planner for bridges and special structures
- » National President of the Association of Civil Engineers in Portugal (1995-1998)
- » President of the European Council of Civil Engineers (1998-2002)
- » Member of the Portuguese Institute for the Architectural Heritage
- » Professor at the Engineering Faculty of the University of Porto
- » Founder of AdFconstructores (Consultant Engineers) in Porto, Lisbon, Belo Horizonte, Sao Paolo.

Höhmann, Rolf

- Rolf Höhmann was born in 1950. He studied architecture and town planning at the Technical University in Darmstadt. As a researcher at this university, he worked on a study on early industrial buildings in the Rhine-Main-Area.
- Since 1987 he runs his own office "Bureau for Industrial Archaeology" in Darmstadt, which is specialised on research, documentation and restoration of the Industrial Heritage, mainly on large-sized objects.
- He is a member of TICCIH and ICOMOS and speaker of the working group Industrial and Technical Monuments of ICOMOS Germany.
- He was and still is engaged in several World Heritage Nominations in this specialised field.

Prof. Dr. Kloos, Michael

- Michael Kloos (1966) is an architect and urban planner. Michael focuses his work on the interface between urban design and the preservation and sustainable development of cultural and urban landscapes.
- Between 1997 and 2003 responsible architect in the Netherlands.
- In 2003, he became a scientific assistant at the Institute for Urban Design and Regional Planning at RWTH Aachen University, Germany. Here, he co-established the UNESCO Chair in World Cultural and Urban Landscapes in 2012.
- Doctors degree in engineering sciences with distinction in 2014.
- Since 2016, Michael runs his own office michael kloos planning and heritage consultancy in Aachen, Germany, and appointment as professor for the Chair of Preservation and Sustainable Development of Historic Urban and Cultural Landscapes at RheinMain University of Applied Sciences, Germany.

Prof. Gentile, Carmelo

- Carmelo Gentile is Engineer, PhD, and Professor of Structural Engineering at Politecnico di Milano.
- He is author or co-author of more than 200 scientific and technical papers in the fields of Bridge Engineering, Cultural Heritage structures, Dynamic tests and continuous monitoring of bridges and historic structures, Earthquake engineering, Modal and structural identification, Structural Dynamics, Vibration-based damage assessment, Microwave Remote Sensing.
- Since 2006, Carmelo Gentile is Director of the Laboratory of Vibrations and Dynamic Monitoring of Structures of Politecnico di Milano and committed of the full-scale testing and/or continuous dynamic monitoring of more than 100 bridges.

Prof. Lemoine, Bertrand

- Bertrand Lemoine is Architect DPLG, Engineer graduated from Ecole Polytechnique and Ecole des Ponts et Chaussées and holds a doctorate in History of Paris from Paris Sorbonne University.
- He is Honorary Research director at the National Centre for Scientific Research (Centre National pour la Recherche Scientifique / CNRS).
- He has written over 40 books and about 1000 articles in the fields of history of construction, architecture, urban development and heritage in the 19th and 20th centuries.
- He is the director of ACIER architectural magazine. He is a member of the Académie d'Architecture in Paris.

Ass. Prof. Dr. Dr. h.c. mult. Machat, Christoph

- Christoph Machat, PhD, Ass.Prof., Dr. h.c.mult., art historian
- 1972-2011 working in monuments' conservation
- since 1984 inside the international ICOMOS structures, numerous publications
- former President and honorary member of CIAV (ISC for vernacular architecture), vice-president ICOMOS Germany
- since 2008 member of the Executive Committee/Board of ICOMOS
- editor of the series "Heritage at Risk" of ICOMOS International.

Dr. Ogletorpe, Miles

- He is Head of Industrial Heritage at Historic Environment Scotland, the public body responsible for safeguarding and promoting the historic environment in Scotland.
- After graduating from the University of Durham, he completed his PhD at the University of Glasgow.
- In 1985 he joined the Royal Commission on the Ancient and Historical Monuments of Scotland in Edinburgh, from where he moved to Historic Scotland in 2007.
- He has been a Board member of The International Committee on the Conservation of the Industrial Heritage (TICCIH) since 2003 and is a technical assessor for the International Council on Monuments and Sites (ICOMOS).
- He has also worked with international partners on industrial heritage, notably in England, Norway, and Japan.
- Most recently, he led the team responsible for preparing the successful World Heritage nomination for the Forth Bridge (inscribed in 2015).

Prof. Dipl.-Ing. Architect Pahl, Burkhard

- 23.06.1955: Date of birth
- 1976 – 1983: Study of Architecture at TH Darmstadt and ETH Zurich, architectural degree (Dipl. Arch.)
- 1983 – 1986: Architectural practice (Lambert und Partner, Ratingen/Düsseldorf), several prizes in competition designs.
- 1986 – 1990: Research and teaching assistant for "design and building construction", Institute of Prof. Dr. e.h. G. Behnisch, TH Darmstadt
- 1990 – Since 1990 architect activity with M. Weber-Pahl
- Several ambitious buildings with innovations in construction and design, f.e. footbridge landscape garden Bochum-West (IBA Emscher Park), Underground-Station Rathausplatz Bochum, FIS-World-cup Ski-Jump-Hill in Willingen.
- Teaching at department 14 of civil engineering, TH Darmstadt for constructional design; member of BDA
- 1997: Appointed to the University of Leipzig, professorship for constructional design including building rehabilitation and history of technology, speaker of the workgroup "Competitions"
- 1999 – 2005: Dean of study affairs, department civil engineering of Leipzig University; project partner for interdisciplinary research projects, f. e. UTN II, EU
- 2005 – Director of Institute of Building Design and Management, (IGB), Leipzig University; head of "Rectorate Committee University Construction Project" at Augustusplatz, TICCIH membership, Board Member of PWP – Planungsgesellschaft Darmstadt.

Dr. Ringbeck, Birgitta

- Dr. Ringbeck, graduated in history of art, archaeology and ethnology, PHD in Münster.
- From 1988 to 1990 she worked on a research project at the Regional Association of Westphalia-Lippe.
- From 1990 to 1997, she was Head of Department of Preservation of Regional Traditions and Culture at the NRW-Stiftung, a foundation for the protection of nature, regional traditions and culture in Düsseldorf, Germany.
- Between 1997 and 2012, she was the director of the Supreme Authority for the Protection and Conservation of Monuments at the Ministry for Construction of North Rhine-Westphalia.
- Since January 2012, coordinates the World Heritage Program in the Federal Foreign Office (Berlin).
- She is the Chairperson of the board of trustees of the German World Heritage Foundation, Delegate to the World Heritage Committee, member of the Council of ICCROM as well as of DUK, ICOMOS, ICOM and TICCIH.
- Her publications include papers on monument conservation, management plans and the UNESCO World Heritage Convention.

Ass. Prof. Dr. Saisi, Antonella Elide

- Antonella Saisi is Architect and PhD in Earthquake Engineering at Politecnico di Milano.
- Since 2001, she is Assistant Professor of Conservation and Restoration of Architecture at Politecnico di Milano.
- Antonella Saisi has a broad research experience in the field of strengthening of historic buildings and diagnosis of the historic materials and structures.
- She is consultant and project manager of investigation for the conservation planning and maintenance, as well as detecting risk/vulnerability factors or monitoring.
- Antonella Saisi published more than 220 scientific papers and holds awards for her publications in the fields of Architectural Preservation and Diagnosis of Historic Structures.

Seyedashrafi, Baharak

- She studied architecture at Shahid Rajaee University, Tehran, and worked as an architect and research assistant in some historical sites for several years in Iran.
- In 2015, She completed her Master degree in World Heritage Studies at Brandenburgische Technische Universität Cottbus.
- Besides, her employment at the office of michael kloos planning and heritage consultancy, she is currently a Doctoral Candidate at RWTH Aachen University on the topic of “Heritage Impact Assessment Methodology in the Context of Sustainable Urban Development”.
- As a specialist in dealing with cultural heritage, Ms Seyedashrafi has been working in the office of michael kloos planning and heritage consultancy since 2016, in particular, Heritage Impact Assessments in Germany and abroad, as well as the development of a management plans.

Tempel, Norbert

- He was born in 1954. Mechanical Engineer (Dortmund University of Technology)
- Conservator, Head of Department “Engineering and Conservation”, Westphalian State Museum of Industry (LWL-Industriemuseum), Dortmund
- Research, publications and lectures in the field of conservation of Industrial Heritage.
- TICCIH (The International Committee for the Conservation of the Industrial Heritage) German National Representative
- Associate Editor of the quarterly IndustrieKultur Magazine (www.industrie-kultur.de).

Univ.-Prof. Dr.-Ing. Trautz, Martin

- Born 1962
- 1982 High-School Diploma at Reuchlin Gymnasium, Pforzheim
- 1989 Diploma at Stuttgart University
- 'Eiserne Brücken im 19.Jahrhundert in Deutschland' (Iron Bridges in the 19th Century in Germany). Supervisor: Univ.-Prof. Dr. Drs. E.h.J. Schlaich
- 1990-1991 Structural engineer at Acer Consultants Ltd., bridge-department, GB- Guildford/Surrey, 1991-1993 Structural engineer at Ove Arup & Partners in Leipzig and Berlin.
- 1993-1997 Research assistant at the SFB 230 ‚Natural Structures' and the Institute for Lightweight-Structures (IL) (Prof. Dr-ing.Dr.h.c.mult. F.Otto) and the Institute of Structural Mechanics (Prof.Dr. E.Ramm)
- 1998 PhD at Stuttgart University
- 'Zur Form und Struktur historischer Gewölbe aus der Sicht der Statik' (Form and Construction of Historical Vaults from a Viewpoint of Statics) Supervisors: Univ.-Prof. Dr.-ing. habil E.Ramm, Univ.-Prof. Dr.-Ing. R.Barthel (TU München)
- 1997-2002 Structural engineer at Bollinger+Grohmann Consultants, Frankfurt/Main.
- since 2002 Office for Structural Design in Aachen and Kelkheim/Ts, since 2010: trako engineering
- since 2005 Head of the chair for structures and structural design at the faculty of Architecture at Aachen University (RWTH Aachen)
- 2011-2014 Dean of the Faculty of Architecture of Aachen University.

Gianpaolo Villa (Assessor, Paderno d'Adda)

- He was born in Lecco on 13th March 1961 and has lived in Paderno d'Adda, Lecco province.
- He has a diploma in Electronics and worked for a multinational company as Product Manager of Software Applications.
- In 1985-1990, he was an assessor to the municipality of Paderno d'Adda, participating to the organization of the San Michele Bridge Centennial celebrations.
- He was nominated Assessor again in 2004 and this is still his current role.

Watson, Mark

- He was born in Scotland and lives in Edinburgh.
- A historian, he works for a national agency in building conservation and has special interests in industrial, urban and world heritage, home and abroad. IHBC, ICOMOS, and TICCIH offer rich subject matter.
- Mark was engaged in the World Heritage nominations of New Lanark and the Forth Bridge.
- He believes the UK cannot avoid its part in a common European home, heritage, and destiny.

Zimmermann, Carsten

- Carsten Zimmermann was born in 1974 in Altenkirchen, Germany.
- From 1994 to 2001 he studied architecture and urban planning at the Rheinisch-Westfälische Technische Hochschule in Aachen.
- From 2001 to 2003 he worked in the office Faltin-Scheuvens-Wachten (FSW) in Aachen and Dortmund as well as at the EU-Regionale 2008 and was there among others responsible for large-scale urban development projects, such as the city center concept of Aachen or the competition of the Aachener Montana region.
- He then completed the two-year town planning traineeship at the district government of Dusseldorf and the city of Solingen, before he started in 2006 at the city planning office Solingen.
- Here he was also responsible for special tasks of the Solingen city director Hartmut Hoferichter.
- From 2008 to mid-2016, he headed the Urban and Regional Planning team at the Bergische Structural and Economic Development Corporation. Under his leadership, significant regional concepts were created and regional construction projects tackled.
- Since mid-2016, he has headed the Strategic Planning Department in the office of Mayor Tim Kurzbach and is responsible for strategically important projects of the city of Solingen.
- Already at the Bergische Structural and Economic Development Corporation, he has initiated the application of the Müngstener Bridge to the World Heritage and is also responsible for the project serial, transnational World Heritage after his move to the city of Solingen.