HISTORY OF CONSTRUCTION CULTURES

VOLUME 2

edited by
João Mascarenhas-Mateus
and **Ana Paula Pires**

CRC Press
Taylor & Francis Group

PROCEEDINGS OF THE 7TH INTERNATIONAL CONGRESS ON CONSTRUCTION HISTORY (7ICCH 2021), LISBON, PORTUGAL, 12–16 JULY 2021

History of Construction Cultures

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CRC Press
Taylor & Francis Group
Boca Raton London New York Leiden

CRC Press is an imprint of the
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A BALKEMA BOOK

Cover illustration: Julia Lyra, PTBUILDS19_20 research project, ref. PTDC/ARTDAQ/28984/2017.

Funded by the Portuguese Foundation for Science & Technology, PTBUILDS19_20 research project ref. PTDC/ARTDAQ/ 28984/2017. Published by Taylor & Francis Group plc.

Typeset by MPS Limited, Chennai, India

Library of Congress Cataloging-in-Publication Data

A catalog record has been requested for this book

Published by: CRC Press/Balkema
Schipholweg 107C, 2316 XC Leiden, The Netherlands
e-mail: enquiries@taylorandfrancis.com
www.routledge.com – www.taylorandfrancis.com

ISBN: 978-1-032-00199-9 (SET Hbk)
ISBN: 978-1-032-00228-6 (SET Pbk)

ISBN Volume 1: 978-1-032-00202-6 (Hbk)
ISBN Volume 1: 978-1-032-00266-8 (Pbk)
ISBN Volume 1: 978-1-003-17335-9 (eBook)
DOI: 10.1201/9781003173359

ISBN Volume 2: 978-1-032-00203-3 (Hbk)
ISBN Volume 2: 978-1-032-00269-9 (Pbk)
ISBN Volume 2: 978-1-003-17343-4 (eBook)
DOI: 10.1201/9781003173434

History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)
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© 2021 Copyright the Author(s), ISBN 978-1-032-00203-3

Introduction: *History of Construction Cultures*

We are what we build and how we build; thus, the study of Construction History is now more than ever at the centre of current debates as to the shape of a sustainable future for humankind. Embracing that statement, the present work takes the title *History of Construction Cultures* and aims to celebrate and expand our understanding of the ways in which everyday building activities have been perceived and experienced in different cultures, times and places.

This two-volume publication brings together the communications that were presented at the 7ICCH – Seventh International Congress on Construction History, broadcast live from Lisbon, Portugal on 12–16 July 2021. The 7ICCH was organized by the Sociedade Portuguesa de Estudos de História da Construção (Portuguese Society for Construction History Studies – SPEHC); the Lisbon School of Architecture, University of Lisbon; its Research Centre (CIAUD); and the College of Social and Human Sciences of the NOVA University of Lisbon (NOVA FCSH).

This is the first time the International Congresses on Construction History (ICCH) Proceedings will be available in open access format in addition to the traditional printed and digital formats, embracing open science principles and increasing the societal impact of research. The work embodies and reflects the research done in different contexts worldwide in the sphere of Construction History with a view to advancing on the path opened by earlier International ICCH editions. The first edition of ICCH took place in Madrid in 2003. Since then, it has been a regular event organized at three-year intervals: Cambridge (2006), Cottbus (2009), Paris (2012), Chicago (2015) and Brussels (2018).

7ICCH focused on the many problems involved in the millennia-old human activity of building practiced in the most diverse cultures of the world, stimulating the cross-over with other disciplines. The response to this broad invitation materialized in 357 paper proposals. A thorough evaluation and selection process involving the International Scientific Committee resulted in the 206 papers of this work, authored by researchers from 37 countries: Australia, Austria, Belgium, Brazil, Bulgaria, Canada, China, Dominican Republic, Ecuador, Egypt, Estonia, France, Germany, India, Iran, Ireland, Italy, Japan, Mexico, Netherlands, New Zealand, Norway, Peru, Poland, Portugal, Puerto Rico, Russia, Serbia, Spain, South Africa, Sweden, Switzerland, Thailand, United Arab Emirates, United Kingdom, United States of America, and Venezuela.

The study of construction cultures entails the analysis of the transformation of a community's knowledge capital expressed in the activity of construction. As such, Construction History is a broad field of knowledge that encompasses all of the actors involved in that activity, whether collective (contractors, materials producers and suppliers, schools, associations, and institutions) or individual (engineers, architects, entrepreneurs, craftsmen). In each given location and historical period, these actors have engaged in building using particular technologies, tools, machines and materials. They have followed specific rules and laws, and transferred knowledge on construction in specific ways. Their activity has had an economic value and belonged to a particular political context, and it has been organized following a set of social and cultural models.

This broad range of issues was debated during the Congress in general open sessions, as well as in special thematic sessions. Open sessions covered a wide variety of aspects related to Construction History. Thematic sessions were selected by the Scientific Committee after a call for proposals: they highlight themes of recent debate, approaches and directions, fostering transnational and interdisciplinary collaboration on promising and propitious subjects. The open sessions topics were:

- Cultural translation of construction cultures: Colonial building processes and autochthonous cultures; hybridization of construction cultures, local interpretation of imported cultures of building; adaptation of building processes to different material conditions;
- The discipline of Construction History: Epistemological issues, methodology; teaching; historiography; sources on Construction History;
- Building actors: Contractors, architects, engineers; master builders, craftspeople, trade unions and guilds; institutions and organizations;
- Building materials: Their history, extraction, transformation and manipulation (timber; earth, brick and tiles; iron and steel; binders; concrete and reinforced concrete; plaster and mortar; glass and glazing; composite materials);

– Building machines, tools and equipment: Simple machines, steam operated-machines, hand tools, pneumatic tools, scaffolding;
– Construction processes: Design, execution and protective operations related to durability and maintenance; organization of the construction site; prefabrication and industrialization; craftsmanship and workshops; foundations, superstructures, roofs, coatings, paint;
– Building services and techniques: Lighting; heating; ventilation; health and comfort;
– Structural theory and analysis: Stereotomy; modelling and simulation; structural theory and structural forms; applied sciences; relation between theory and practice;
– Political, social and economic aspects: Economics of construction; law and juridical aspects; politics and policies; hierarchy of actors; public works and territory management, marketing and propaganda;
– Knowledge transfer: Technical literature, rules and standards; building regulations; training and education; drawings; patents; scientific dissemination, innovations, experiments and events.

The thematic sessions selected were:

– Form with no formwork (vault construction with reduced formwork);
– Understanding the culture of building expertise in situations of uncertainty (Middle Ages-Modern times);
– Historical timber constructions between regional tradition and supra-regional influences;
– Historicizing material properties: Between technological and cultural history;
– South-South cooperation and non-alignment in the construction world 1950s–1980s;
– Construction cultures of the recent past: Building materials and building techniques 1950–2000;
– Hypar concrete shells: A structural, geometric and constructive revolution in the mid-20th century;
– Can engineering culture be improved by construction history?

Volume 1 begins with the open session "Cultural translation of construction cultures" and continues with all of the thematic sessions, each one preceded by an introductory text by the session chairs. The volume ends with the first part of the papers presented at the open sessions, organized chronologically. Volume 2 is dedicated to the remaining topics within the general themes, also in chronological order.

Four keynote speakers were chosen to present their most recent research results on different historical periods: Marco Fabbri on "Building in Ancient Rome: The fortifications of Pompeii"; Stefan Holzer "The role of temporary works on the medieval and early modern construction site"; Vitale Zanchettin "Raphael's architecture: Buildings and materials" and Beatriz Mugayar Kühl "Railways in São Paulo (Brazil): Impacts on the construction culture and on the transformation of the territory".

The editors and the organizers wish to express their immense gratitude to all members of the International Scientific Committee, who, despite the difficult context of the pandemic, worked intensively every time they were called on to give their rigorous evaluation of the different papers.

The 7ICCH was the first congress convened under the aegis of the International Federation of Construction History, founded in July 2018 in Brussels. Therefore, we are also very grateful to all the members of the Federation, composed of the presidents of the British, Spanish, Francophone, German, U.S. and Portuguese Societies and its Belgian co-opted member. A special thanks is due for all the expertise and experience that was passed on by our colleagues who have been organizing this unique and world significant event since 2003, and in particular to our predecessors from all the Belgian universities who organized 6ICCH.

The editors wish to extend their sincerest thanks to authors and co-authors for their support, patience, and efforts. This two-volume work would not exist but for the time, knowledge, and generosity they invested in the initiative.

Our sincere thanks also go out to Kate Major Patience, Terry Lee Little, Kevin Rose and Anne Samson for proofreading every paper included here, and to the team at Taylor & Francis (Netherlands), in particular Germaine Seijger and Leon Bijnsdorp.

Finally, we are grateful to all members of the Local Committee and to the institutions that have supported both the 7ICCH event and the publication of these proceedings.

The Editors
João Mascarenhas-Mateus and Ana Paula Pires

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Open session: Construction processes

History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Pneumatic foundations in the bridges of the first Italian railways

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ABSTRACT: In the first half of the 19th century the French geologist Jacques Triger developed a construction process useful for excavating waterlogged soils that applied a caisson to pump compressed air into the working site. His invention was widely deployed in construction engineering, especially for sinking bridge pier foundations in riverbeds. This technology was first used in Italy in the 1850s under the supervision of British and French building companies. It served for the construction of many bridges in the new Italian railway network and resulted from a fruitful collaboration between Italian and foreign technicians. This essay will describe the evolution of cast iron and wrought iron caissons in Italy, a country which provided a favorable environment for the experimentation of this new technology.

1 ITALIAN RAILWAYS: PNEUMATIC FOUNDATIONS FOR NEW BRIDGES

In the first half of the 19th century, the political division of the Italian territory led to the discontinuous and complicated development of the railway network. In 1840s, after the first line between Naples and Portici was completed in the Kingdom of the Two Sicilies in 1839, initial railways began being built by the peninsula's individual states with their different technical and economic means. Furthermore, there were no coordinated plans between the states that guaranteed efficient connections between the country's main cities (Briano 1977).

In addition to difficulties in attracting resources and the complicated dialogue between governments, other problems arose due to geographic obstacles. They sometimes entailed the choice of irregular routes in order to avoid the inevitable technical and financial commitments needed for the construction of bridges and viaducts, necessary for more direct connections between destinations.

One of the greatest difficulties related to bridge building was the construction of bridge foundations in riverbeds. This was usually solved using traditional techniques that had various limitations. For example, the Venetian Lagoon railway bridge, inaugurated in 1846 under Austrian rule, used deep foundations built of larch and oak poles. These were fixed into the ground and connected at the top to wooden boards that supported the masonry required for the over two hundred arches that made up the bridge. For other bridges over narrow and shallow rivers, centuries old technology was used requiring the deviation of the watercourse or the insertion of bulkheads in order to carry out excavations in the open air. However, the use of these techniques was only possible in shallow waters when the foundations did not reach more than 6–7 meters below ground level (Predari 1867).

In the 1840s, the development of pneumatic foundations, tried out first in Britain and France, revolutionised the way of building underwater: the new procedure avoided the insertion of bulkheads and allowed for deeper and continuous excavations and required a smaller workforce.

Pneumatic foundations were required in Italy for the construction of the bridges necessary for an efficient national rail network but the backwardness of local companies and industries led to the initial assignments for these works being awarded to foreign companies already able to apply the new technology. In particular, between the 1850s and 1870s, firstly in the Kingdom of Sardinia and then in the Kingdom of Italy, British and French companies, finding an ideal place of application and research in the country, collaborated with local technicians and deployed different types of pneumatic foundations for the first time in Italy.

2 ORIGINS AND DEVELOPMENT OF PNEUMATIC FOUNDATIONS

The mining industry was one of the main promoters of studies concerning the use of compressed air. Already in the 17th century, the requirement for underground ventilation had led to the development of the first compressors, able both to produce air at a higher pressure than the surrounding atmosphere and to diffuse it into any work space through a network of pipes (Drinker 1883).

Compressed air played a crucial role in the extraction of coal from underground and underwater deposits. In 1841, Jacques Triger used it to extract coal from a deposit below the River Loire near the town

 DOI 10.1201/9781003173434-120

of Chalonnes. In order to guarantee a dry work space, Triger developed a sheet iron tube, open at the base and closed at the top, from which the water was expelled by pumping compressed air into the tube. The tube was composed of rings with a diameter of one meter. These were connected to each other with fishbolts and made watertight using leather strips. In the upper section, an airlock regulated the air pressure and the entry and the exit of workers.

The airlock was an evolution of the early diving bell, also known as "cloche de plongée", developed in the 18th century that enabled the carrying out of the first deep underwater explorations, aimed at recovering cargo from sunken ships. The physicists Smeaton and Coulomb saw its potential value in the building sector (Curioni 1868).

The tube was gradually sunk into the riverbed with the help of upper loads with the interior lighting provided by stearic candles or gas lamps. The air pressure had to be kept below four atmospheres in order not to compromise the health of workers.

Triger's process received coverage in the publications of the time and showed more advantages than the Potts' system patented in the same period in Britain. The Potts' system was based on reducing the air density inside the tube so as to suck up water and sediments and to ease penetration into the soil but also entailed the regular suspension of work in order to empty the tube when full of deposits (Dempsey 1855).

The process developed by Triger began to be applied in other sectors and within a few years was being used in the construction of underwater foundations in incoherent soils. Previously they had needed very long poles which, due to their length, were susceptible to shear stresses. By the late 1840s, Triger's process was under applications in France, Britain and the United States for constructing bridge piers.

In 1851, for the construction of Rochester Bridge, the British engineer John Hughes introduced important innovations: he enlarged the airlock, equipped it with a double compartment in order to improve the regulation of the air pressure (Figure 1) and optimised the construction process by combining the Triger and Potts systems (Hughes 1859).

A few years later, the company responsible for building the bridge over the River Medway was involved in the construction of bridges in the new Italian railway network.

3 PNEUMATIC FOUNDATIONS WITH CAST IRON TUBES: THE SAVOY BRIDGES

Under the governance of the Count of Cavour, there was a decisive turning point in the drive towards industrial and infrastructural progress for the Kingdom of Sardinia. The Piedmontese statesman, who considered railways an effective means for economic and cultural development, initiated a series of projects for the construction of new railway routes that played an important role even after the Unification of Italy.

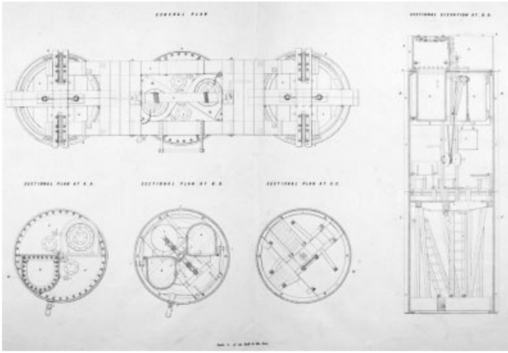

Figure 1. Rochester Bridge: the caissons built in 1851 by Fox & Henderson Company (Hughes 1859).

Between 1852 and 1853, Cavour worked on completing the line between Turin and Genoa but, above all, he provided for the construction of new lines dedicated to international connections, in particular links with Lombardy, then in Austrian territory, France and Switzerland (Cavicchioli 2009).

For the line between Turin and Novara, which was later extended to connect with Milan, Cavour signed an agreement with a group of British entrepreneurs guided by the well-known contractor Thomas Brassey (Stefani 1853), the designer of several railways in Great Britain and Europe and who had managed to complete 100 km of railways in three years. For the line between Turin and Culoz, also known as the Fréjus railway, the Vittorio Emanuele company was founded in 1853, backed by French financiers who also acquired control of the line to Milan after a few years.

The crossing of rivers in a mountainous area involved the construction of railway bridges and viaducts, which required recourse to pneumatic foundations.

3.1 *Pneumatic foundations of the bridges built in the railway line between Turin and Novara*

Thomas Brassey entrusted the construction project for the railway line between Turin and Novara to the British engineer Thomas Jackson Woodhouse. The two had already collaborated in Italy, building the the line between Prato and Pistoia. The engineer Edward Francis Murray, who was involved in completing the railway line between Turin and Genoa, together with Woodhouse and the Italian engineers C. Bermani and V. Ferrari designed four bridges built over the Rivers Stura, Orco, Mallone and Agogna (Murray 1883).

They used the same layout: continuous deck bridges sustained by four supports, two of which were placed in the riverbed. Two wrought iron girders, stiffened using a riveted lattice between the chords, and vertical members supported the single rail (Figure 2).

The use of cast iron tubes sunk into the ground using Triger's pneumatic process was chosen for the bridge

Figure 2. Railway bridge near Novara: the piers built in 1855 by the same company of Rochester Bridge (Fassò 1880).

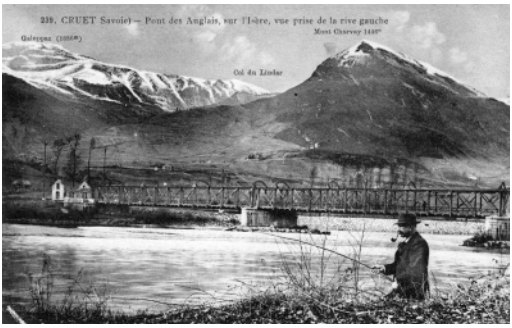

Figure 3. Railway bridge over the River Isère near Cruet: the continuous wrought iron truss (Goutagny Postcard 1889).

Figure 4. Cruet Bridge: a pier and its upper rubble masonry sustained by pneumatic foundations (Decker 2020).

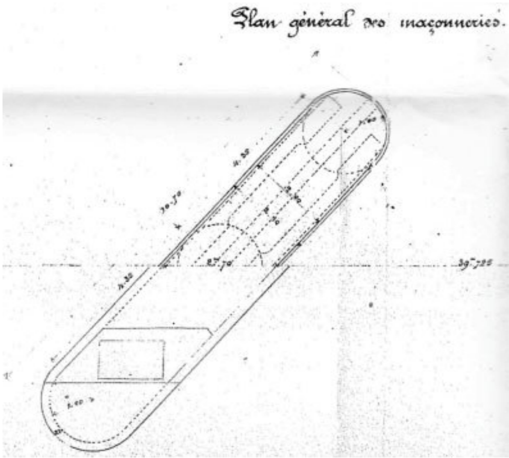

Figure 5. Cruet Bridge: the arrangement of the cast iron tubes and their connections (Courtesy of ACN&P).

piers and the project was managed by Fox & Henderson Company, known for their participation in the construction of Crystal Palace in London and also for setting the foundations for the bridge over the River Medway in Rochester (Casalis 1855).

For each pier they used two cast iron cylinders, which were between 7 and 10 meters long and made of rings, with the height and diameter both measuring 1.5 meters. The sinking was carried out by creating an airlock at the top of the tubes that ensured the regulation of compressed air which was injected by a steam pump. Once the water had been expelled from the tube, the excavation was carried out by two workers, assisted from the outside by two co-workers.

The sinking of the tubes was rapid: for the bridge over the River Agogna near Novara, each cast iron cylinder was sunk to a depth of 7 meters in a period of between two and three days. Once sunk, the tubes were filled with concrete and then connected at the top by wrought iron beams that supported the masonry works.

Above the tubes, walls also acted as the formwork for a further cast of concrete that stabilised the sinking of the cylinders (Pozzi 1892). The technology applied in the piers of the four bridges of the line between Turin and Novara was also used in Savoy, where some innovations developed in France were also introduced.

3.2 *Pneumatic foundations of the bridges built in the railway line between Turin and Culoz*

The rail connection between Turin and Savoy, which was part of the Kingdom of Sardinia until 1861, was a complex challenge. The Alpine mountains did not allow for any direct route and furthermore needing the construction of a tunnel through Mount Fréjus.

For the laying of the track beyond the tunnel, between Modane and Chambéry, the Vittorio Emanuele Company once again involved Thomas Brassey. George Neumann, a British engineer who had trained in Switzerland and France, was commissioned to design the railway line (Neumann 1867).

Neumann also oversaw the construction of two important bridges: one over the River Isère near Cruet and another over the River Rhone near Culoz on the French border. Both involved the use of large spans, greater than 150 meters, and a structure with a continuous truss supported by multiple piers (Figures 3 and 4).

The truss was built of riveted profiles with different sections and was visually characterized by the way in which these diagonal braces were inserted in the spaces between the chords and vertical members with the arch shaped portal struts (Messiez 1992).

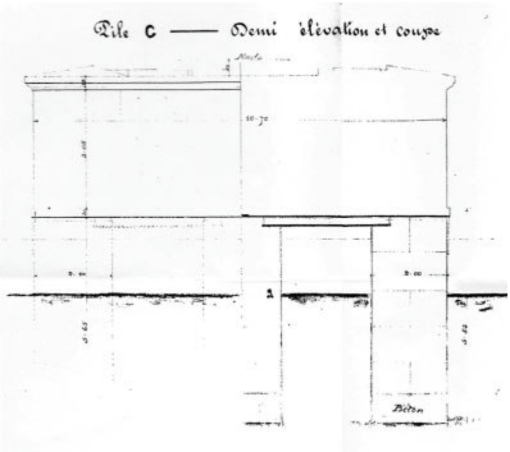

Figure 6. Cruet Bridge: the depth of the cast iron tubes and their concrete filling (Courtesy of ACN&P).

Figure 7. Culoz Bridge over the River Rhone: the same truss used near Cruet (Ministère des travaux publics 1873).

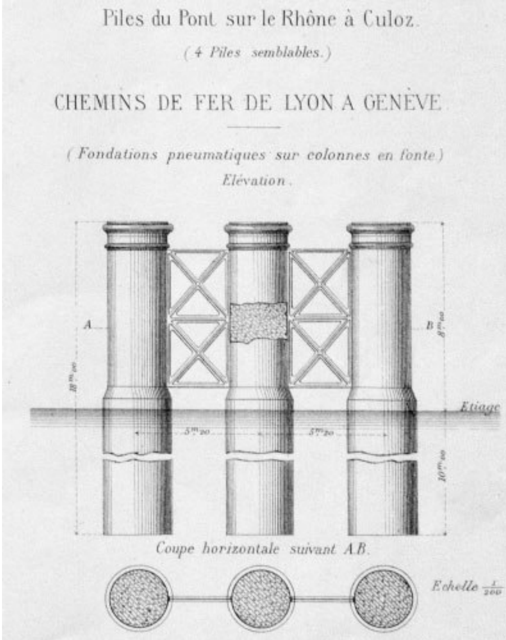

Figure 8. Culoz Bridge: the geometry and connections of the cast iron cylinders (Goüin 1878).

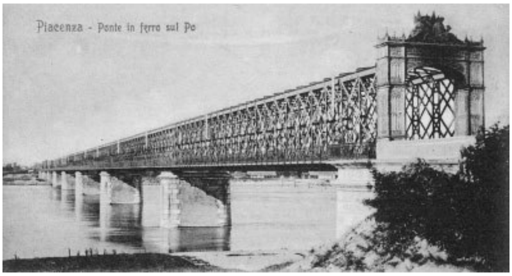

Figure 9. Railway bridge over the River Po in Piacenza: the piers built by a French company (Bernardi Postcard 1890).

The piers of the two bridges were built with pneumatic foundations. Different companies were involved in their construction, each with their own technical solutions.

The same company as commissioned by Brassey for the bridges on the line between Turin and Novara participated in the piers for the Cruet bridge, also known as Pont des Anglais. The larger dimensions of the bridge required the adaptation of devices used in the construction process.

Three cast iron cylinders were used for each pier, each with a diameter of two meters (Figure 5). These were sunk to a minimum of four meters below ground level. In addition to the wrought iron beams joining the top of the tubes, the connection was also made using a one meter high iron sheet to delimit the edge of the masonry (Figure 6). The upper part of the piers was a rubble masonry with stone ashlars on the perimeter and a concrete filling that formed a massive and compact element (Decker 2020).

The construction of the Culoz bridge, which marked the border between the Kingdom of Sardinia and France, entailed a collaboration agreement between different companies from the two countries. The iron deck was built by the Vittorio Emanuele Company, who chose the same deck designed for the Cruet bridge and decorated it with the French and Savoy coat of arms. The foundations and other riverbed improvement works were managed by the Society of Lyon-Geneva Railway Line, which commissioned Ernest Goüin et Cie Company to build the piers (Figure 7). Between 1856 and 1857, twelve cast iron cylinders were sunk below the riverbed to a depth of 10 meters using Triger's procedure and filled with concrete (Park-Barjot 2005). Unlike on previous bridges, the Parisian company did not carry out masonry work but extended the height of the tubes. These were connected three by three by wrought iron trusses and directly supported the deck (Figure 8). With this solution, the piers were less bulky giving the bridge a greater visual permeability (Goüin 1878).

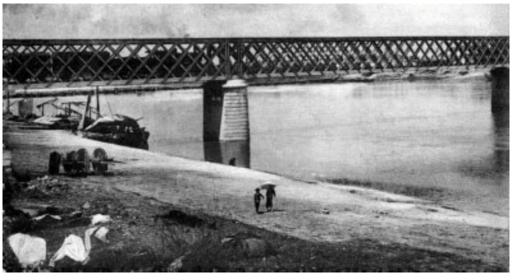

Figure 10. Railway bridge near Pontelagoscuro: the piers built with wrought iron caissons (Prampolini Postcard 1902).

Other railway bridges were built after the Unification of Italy with all benefiting from the technical advancements surrounding pneumatic foundations.

4 PNEUMATIC FOUNDATIONS WITH WROUGHT IRON CAISSONS: THE BRIDGES OVER THE RIVER PO

Developing the railway network also remained one of the main objectives for the new Kingdom of Italy, which was finally able to link the partially built lines in its different regions.

In particular, the government focused on connecting the lines between Lombardy, Emilia Romagna and Veneto, separated by the River Po, which was difficult to traverse and between 300 and 400 metres wide in places. After the examination of the available resources and possible technical solutions, the construction of various bridges over the river began in 1861. These included the four bridges necessary to complete the Milan-Genoa, Milan-Piacenza, Ferrara-Rovigo and Mantua-Modena railway lines (Besso 1870).

The respective locations chosen were Piacenza, Mezzana Corti, Pontelagoscuro and Borgoforte with the same structural layout chosen: a wrought iron truss in the upper part, which was able to outdistance the supports as much as possible, and with tall piers in the lower section to contain the river in case of flooding. The piers had to be fixed into the riverbed using Triger's process, which had itself undergone some improvements.

At the end of the 1850s, for the Saltash bridge over the River Tamar near Plymouth, the engineer Brunel improved the process by dividing the space between the walls of the cast iron cylinder with diaphragms. This was useful for differentiating the compressed air input channels from those for excavated materials and workers. For the bridge over the River Rhine in Kehl near Strasbourg, the engineer Fleur St. Denis, mindful that the greater depth of the tubes sometimes compromised their verticality, experimented with using a wrought iron caisson which was as large as the upper part of the pier and had a cutting edge at the base (Bruno 1892).

Thanks to the Fleur St. Denis innovation, wrought iron caissons were rapidly preferred to cast iron cylinders, indeed the new devices were used for the piers of the River Po bridges. In particular, the bridges in Piacenza and Pontelagoscuro represent the most significant cases regarding the first Italian application of this foundation type (Figures 9 and 10).

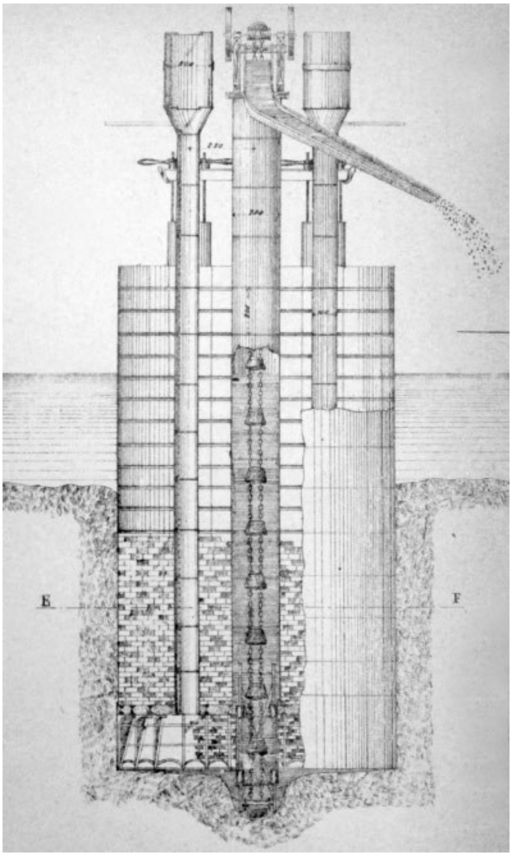

Figure 11. Piacenza Bridge: the sinking process and wrought iron caisson equipped with three tubes (Biadego 1886).

4.1 *Pneumatic foundations of Piacenza Bridge*

The design of the bridge linking the railway line between Milan and Piacenza was supervised by the engineer Giovanni Battista Biadego, who chose a continuous wrought iron truss 280 meters long and supported by seven piers placed in the riverbed. The works were entrusted to the Parent, Schaken, Caillet et Cie Company, based in Fives-Lille and directed by the engineer Félix Moreaux, who had also participated in constructing the bridge in Culoz.

All the piers were 30 meters high. They were sunk into the ground reaching a depth of 20 meters using pneumatic caissons similar to those used two years earlier in Kehl and now applied in Italy for the first time. Each caisson was made of riveted wrought iron sheet that was 1.2 cm thick. It was open at the base with a cutting edge and closed on the top, forming a work space 2.2 meters in height. Three wrought iron

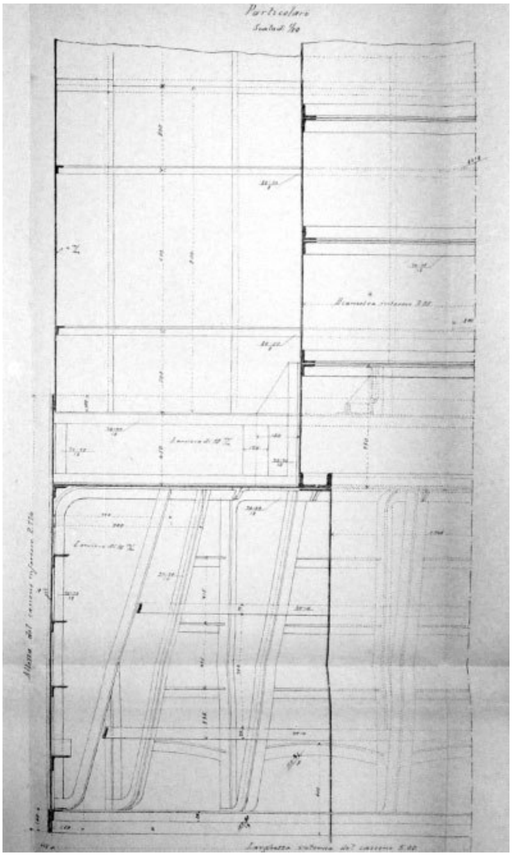

Figure 12. Piacenza Bridge: the construction details of the wrought iron caisson (Biadego 1886).

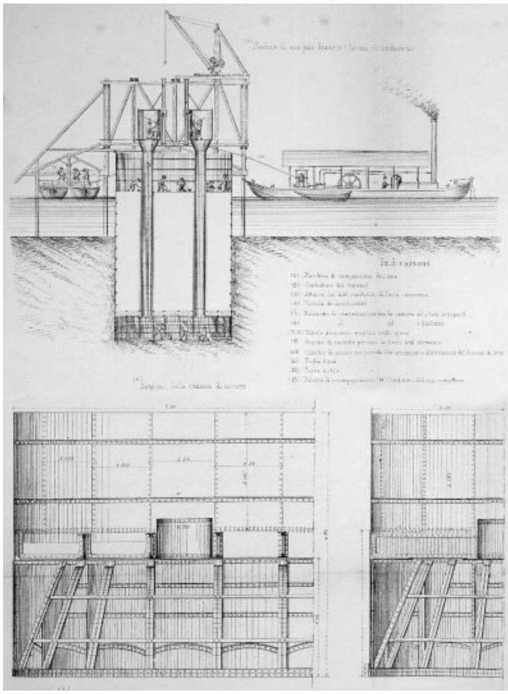

Figure 13. Pontelagoscuro Bridge: the sinking process of the piers and construction details of the caisson (Ratti 1876).

tubes were joined to the ceiling of this space: two were equipped with airlocks on the top and were used for the compressed air regulation and the passage of workers; another included a dredge which excavated and lifted earth (Figure 11).

The ceiling of the caisson was stiffened with iron I beams and served as formwork for the upper masonry works (Figure 12). The Piacenza Bridge was also the first in Italy to be equipped with new systems of natural and artificial lighting: convex lenses were located in the airlock roof and electric lamps illuminated the work space and had the advantage of not consuming oxygen.

The construction of each pier from start to finish was carried out by a team of only ten workers. They were also responsible for the eight hoists used to keep the caissons horizontal. The hoists were set on a temporary wooden bridge, built to facilitate construction. The workers also undertook the filling of the work space and chimneys with concrete at the end of the sinking phase.

The construction of the piers began in August 1862 but the collapse of a section of the temporary wooden bridge caused a year-long suspension of work. After the reorganization of the construction site and the recovery of the materials, work continued and was completed in 1865 (Biadego 1886).

4.2 *Pneumatic foundations of Pontelagoscuro Bridge*

The line between Bologna and Pontelagoscuro had opened in 1862 and connecting it with Venice required a bridge over the River Po spanning over 350 meters.

The bridge was designed by the engineer Gaetano Ratti with a continuous wrought iron truss supported by five piers set in the riverbed. Unlike the bridge in Piacenza, the truss was composed of U profiles for the chords and I profiles for the diagonal braces, without any internal vertical members. The works were conducted by the same French company, with the collaboration of the entrepreneur Jean-François Cail, who had also been involved in the construction of several European railways.

As with the Piacenza bridge, the company applied wrought iron caissons for the piers and developed a new system for transporting the excavations. This was designed by the director Moreaux and partially experimented the works of Mezzana Corti Bridge.

The dredger usually placed in the central chimney, often caused imbalances in the compressed air in the work space and sometimes the chimney got obstructed by excavated material. In order to solve these problems, Moreaux developed a caisson that was 11 × 5 meters wide, with two chimneys equipped with airlocks that participated in the excavation movements

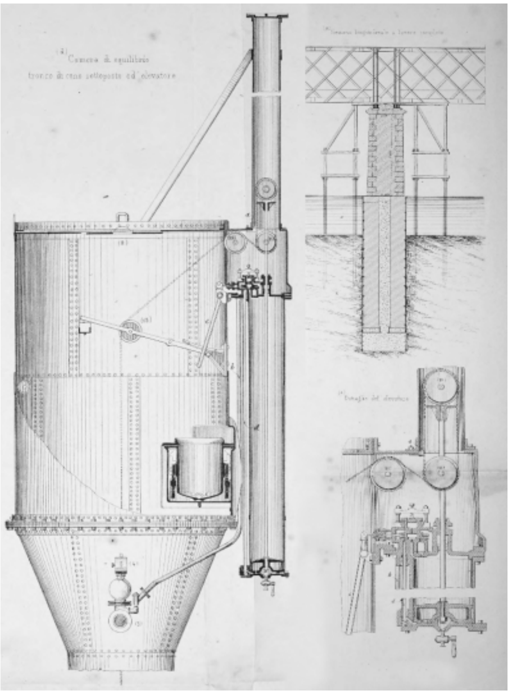

Figure 14. Pontelagoscuro Bridge: the airlock designed for the side piston and the airtight bucket (Ratti 1876).

Figure 15. Sesto Calende Bridge: the piers built by the Italian Industry of Metal Construction (Fotocromo Postcard 1902).

while limiting the loss of compressed air. A three meter high cylinder, with a diameter of 25 cm, was joined to the airlocks with a compressed air powered piston inside (Figures 13 and 14). This piston controlled ropes and pulleys that were managed by a worker who received the excavated material coming up from the work space.

The full buckets emptied into a container affixed to a trolley which, on being pushed outside, automatically introduced an empty container into the airlock.

Local materials, such as concrete made from Palazzolo and Domegliara limestone, were used for the upper masonry. The works began in 1870 and finished the following year in accordance with the system patented by the company (Ratti 1876).

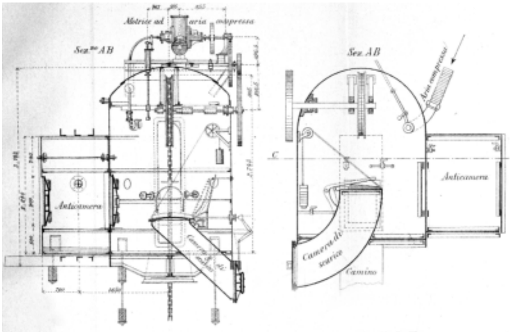

Figure 16. Sesto Calende Bridge: the addition of an antechamber and a discharge pipe to the airlock (Bruno 1892).

Further innovations to the construction process did not change substantially. Advancement focused on mechanizing the airlock, optimizing the compressed air seal and more efficient removal of the excavated materials.

5 CONCLUSIONS

Between the 1850s and 1870s, the deployment of pneumatic foundations was crucial in the conception and construction of the infrastructures necessary for national economic and commercial growth.

The early assignment of these works to British and French companies highlighted the backwardness of the Italian construction sector with this scenario only beginning to change at the end of the 1870s with the affirmation of national companies such as the Italian Industry of Metal Construction. It was the first to use cast iron cylinders for constructing the Ripetta Pedestrian Bridge, built in Rome in 1878, and wrought iron caissons for the railway bridge built over the Ticino River in Sesto Calende in 1882 (Carughi 2003).

For the bridge in Sesto Calende, designed by the engineer Giovanni Battista Biadego (Figures 15 and 16), the company directed by Alfredo Cottrau applied airlocks that followed the model of those used at Pontelagoscuro with the only changes being the addition of an antechamber and further means for casting concrete (Biadego 1886). These technical solutions demonstrated the skills built up by national companies, now finally able to manage imported technological innovations and compete at the European level.

ACKNOWLEDGEMENTS

A special thanks to the staff of the State Archives of Turin for their help in researching documents on the first railways in Piedmont.

We would also like to express our gratitude to Robert Porret of Société Savoisienne d'Histoire et d'Archéologie (SSHA) and Roger Decker of the Association Cruet Nature & Patrimoines (ACN&P) for documents and pictures regarding the Savoy bridges.

We also thank the staff of five libraries for help in researching documents regarding foreign and Italian bridges: E-Rara Bibliothek of ETH Zürich, British Library of London, Biblioteca Boaga of Rome La Sapienza, Biblioteca Centrale di Ingegneria of University of Padua and Biblioteca Civica Carlo Negroni of Novara.

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