



Footbridges - Small is beautiful



Footbridges
Medieval für die Anzeit
Small is beautiful



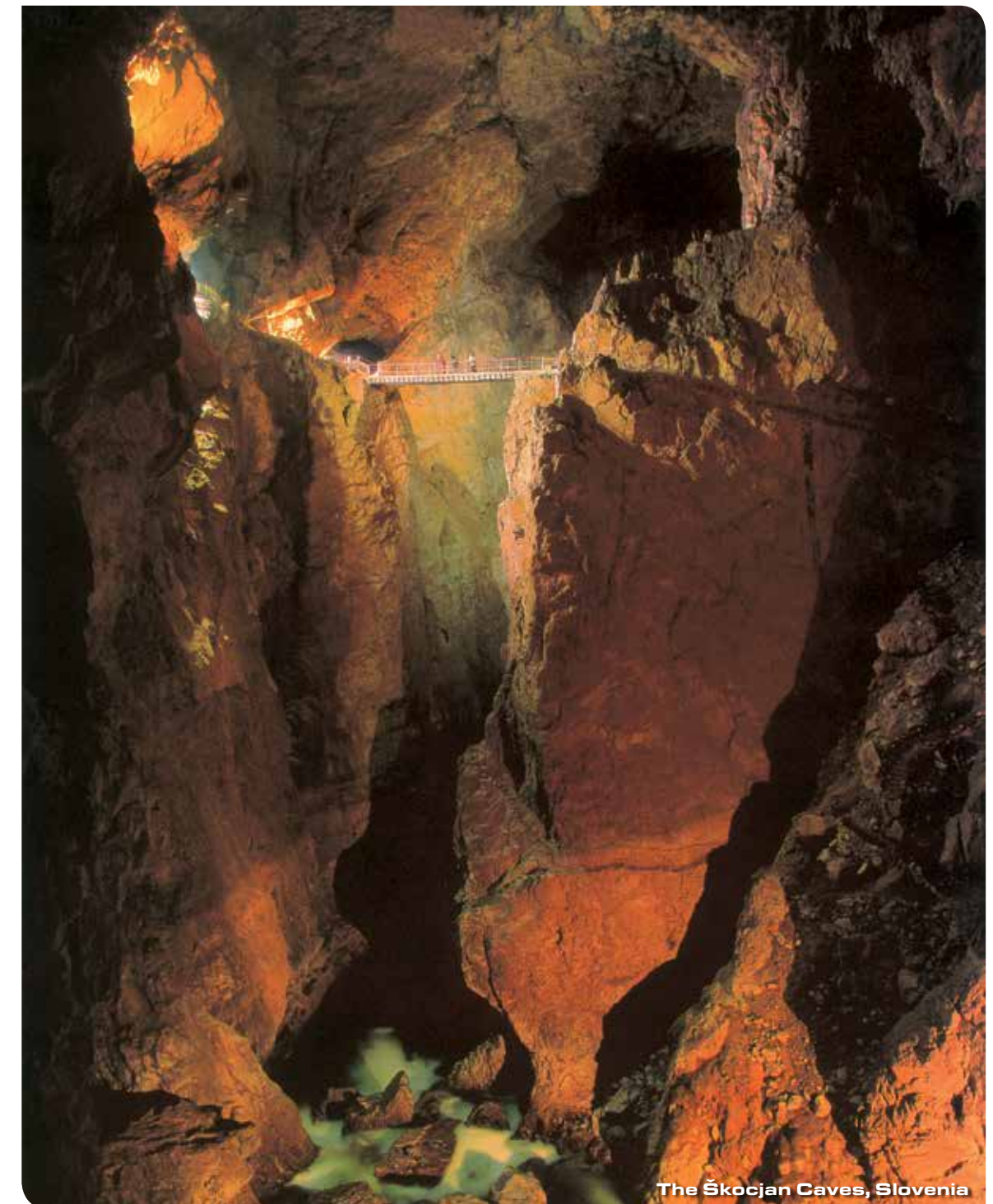


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** The contribution of JSCE-Japan Society of Civil Engineers as guest



The Škocjan Caves, Slovenia

Some notes on the history of bridge structures

Written by Gorazd Humar, B.Sc.C.E., ©

Review: prof. Enzo Siviero, Faculty of Architecture, Venice



Claude Monet (1840–1926)
Le Pont Japonais (The Japanese Bridge)



Hrdeckega Footbridge in Ljubljana, Slovenia, 1867

The article that follows does not aim to describe the entire history of construction, or more particularly of bridge-building, since it does not cover the whole of the historical period in which bridges have been built. The text is a compilation of the author's independent research and a number of his studies relating to the history of bridge-building. It also includes material that the author presents to students in his lectures on the history of construction at the University of Maribor's Faculty of Civil Engineering. The text also contains significant statements and findings from numerous researchers of the history of construction. The author has combined their findings into the overall context of the article according to the logic of their development over time and their importance, and according to his own judgement, so that the text before you can tell the story, supported by historical facts, of the development of bridge-building expertise up to the beginning of the twentieth century.

Some statements and findings are dealt with in more detail because of the interesting points they raise, and serve to make the varied history of construction even more interesting. Why can't the history of construction, and particularly the history of bridge-building, be read like a thrilling novel? The many famous builders and engineers who have built bridges have supplied more than enough reasons to suggest that it can. So let us begin...

Some notes on the history of bridge structures

The foundations of modern structural mechanics are laid in the 17th and 18th centuries



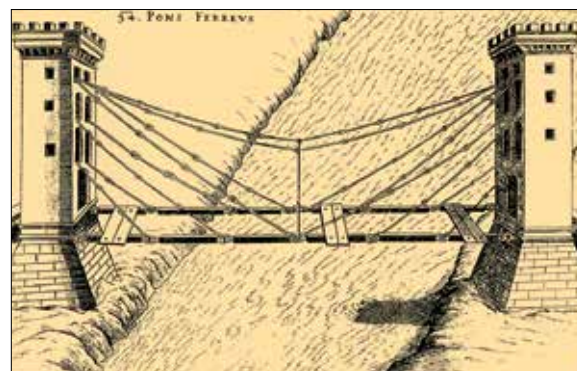
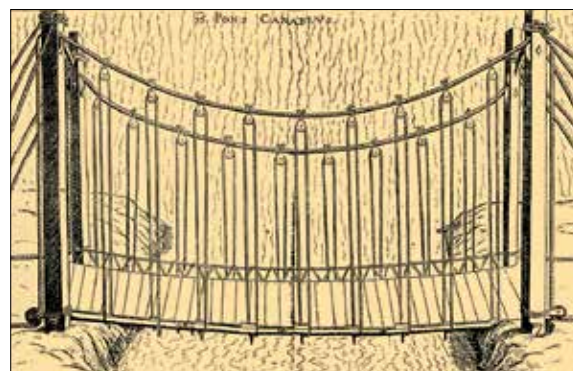
Galileo Galilei (1564–1642)

As mentioned earlier, the construction of the Santa Trinita bridge in Florence in 1569 represented a true turning point in the understanding of structural mechanics and, consequently, the line of the arch. The new line of the flattened arch establishes an entirely new understanding of the interplay of gravitational and other forces in the bridge structure. The arch has long since ceased to be the semi-circular form used in ancient Rome. It has become increasingly flattened, but the most important thing is that the line of the arch of the Santa Trinita bridge is very close to a catenary, in other words a curve that increases its curvature as it moves from the centre of the arch towards the abutments. In this way the horizontal forces in the centre of the arch are increasingly transformed into vertical forces in the pier or abutment.

The research by Ammannati, the builder of the Santa Trinita bridge, into the interplay of forces in a catenary was successfully continued by one of the fathers of modern mechanics, Galileo Galilei (1564–1642), who was not only famous as an astronomer. As well as establishing the laws of falling bodies, Galileo attempted to determine the path of projectiles. He established that the path of a horizontally thrown object is a perfect parabola. In 1638 he succeeded in proving that a parabolic trajectory corresponds to a catenary. Essentially, the interplay of forces in an arch bridge structure of catenary shape is similar to that in a falling projectile.

Also dating from this period is the first known proposal to build a bridge suspended on chains. This was the work of the Croatian inventor and engineer Faustus Verantius (also known as Faust Vrančić or Fausto Veranzio). His work *Machinae Novae*, published in 1595, contained his idea for a bridge suspended from chains. This was the first predecessor of a system for the construction of suspension bridges that was widely used in later centuries and is still used today.

Plans for suspension bridges by the Croatian inventor Faustus Verantius (Faust Vrančić), 1595



Some notes on the history of bridge structures

Of enormous importance for the further understanding of structural mechanics was the research conducted in the seventeenth century by Robert Hooke (1635–1703). He discovered the law of elasticity – known as Hooke’s Law – which is still valid today.

The most solid foundations of modern structural mechanics were, however, laid by Sir Isaac Newton (1642–1727). He presented his research in his 1687 work *Philosophiæ Naturalis Principia Mathematica*, condensing it into the laws that we know today as Newton’s laws. Newton’s discoveries opened the way to further development of the science of construction.

A crucial turning point in the history of bridge-building came when Jean-Rodolphe Perronet (1708–1794) established the *École des Ponts et Chaussées* (School of Bridges and Roads) in France in 1747. This school provided the basis for the construction of bridges according to the engineering principles of statics, strength of materials, mechanics and other parallel sciences that contributed, in a scientific manner, to the introduction of new construction principles in bridge-building that were supported by calculations. Perronet’s contribution to the further development of bridges is of inestimable importance. With the help of the findings of his school, he entirely changed the shape of the arch as the principal load-bearing element of the bridge. He flattened the arch to a remarkable degree and in doing so did away with all previous conceptions of arch design in bridge structures.



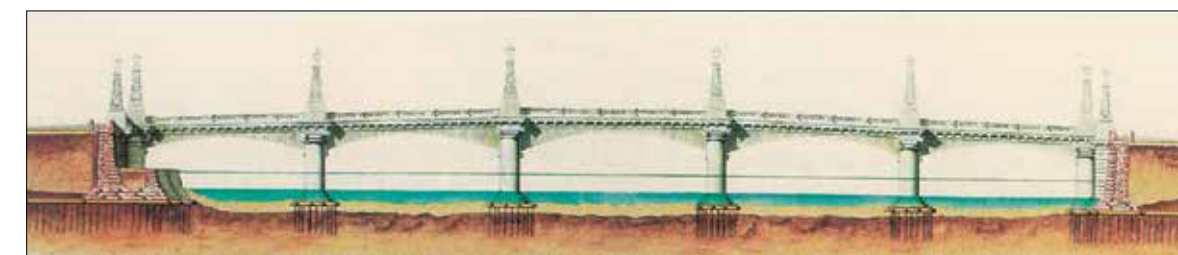
Robert Hooke (1635–1703)



Jean R. Perronet (1708–1794)

Comparison of progress in bridge-building from the Roman era to the 18th century, when J.R. Perronet distinctly modernised the form of the arch and changed the role of piers.

In the picture are the Pont de la Concorde, designed by Perronet, and the Pons Milvius in Rome. Around 1800 years separate the building of these two bridges. While semicircular arches and thick piers were typical of Roman bridges, Perronet’s stone bridges had very shallow arches and slender piers, which among other things allowed more water to pass under the bridge



St John Nepomucene - Svatý Jan Nepomucký
Protector against floods and also protector of bridges

Statues, monuments and inscriptions are not a very common phenomenon on bridges in general. Only a few bridges can boast this type of decoration, which can give a bridge a special importance. The ancient Romans used to build stone tablets into their bridges, usually to commemorate the ruler responsible for its construction. By virtue of their function, bridges were structures on which rulers and others liked to place monuments or divine symbols. No-one could cross the bridge without observing the symbol on it.

Erecting statues or commemorative symbols on bridges reached the height of its popularity in The Middle Ages. Perhaps the richest and most beautiful bridge from this point of view is the Charles Bridge in Prague, built over the Vltava in the early 15th century. Today over 30 statues and sculptures stand on the 516-metre-long bridge, transforming it into a true art gallery.

The old Roman bridge (built 133-134 AD by the Emperor Hadrian) leading to the Castel Sant'Angelo in Rome was completely renovated during the Roman baroque period, by

The Charles Bridge in Prague



Croatia



Footbridges of Dubrovnik

■ Dubrovnik

■ 1397–1538

■ Access bridges to the walls of Dubrovnik

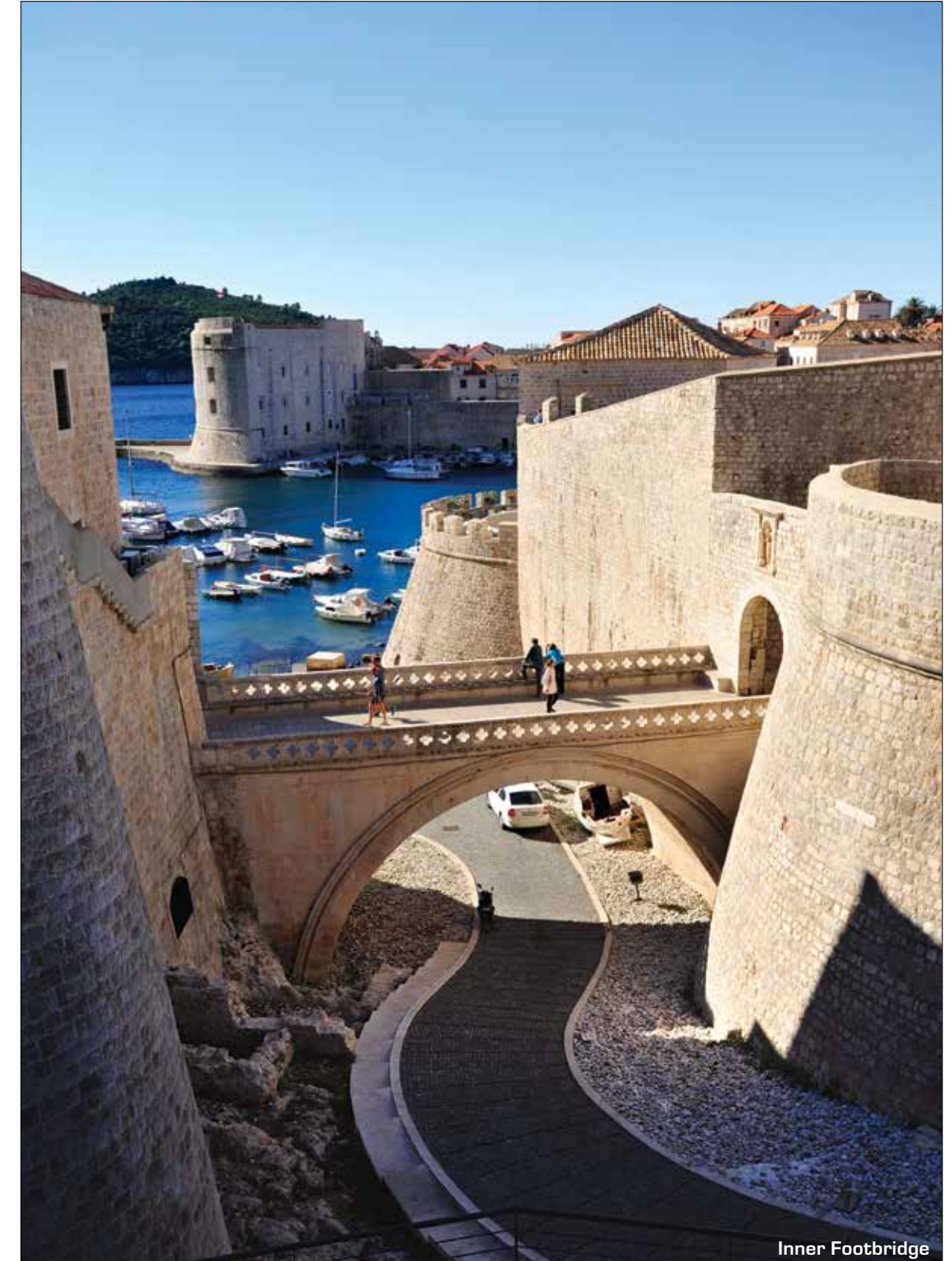
■ Outer bridges extended by a wooden drawbridge

For more than eleven centuries, until the beginning of the nineteenth century, the city of Dubrovnik (Latin: Ragusa) was a republic, defending its survival and freedom primarily through diplomacy but also by building city walls and other fortifications. The Dubrovnik city walls run uninterrupted for 1,940 metres and represent a unique example of fortification architecture. Today they are an internationally recognised monument. The process of constructing the walls and fortifications continued for centuries. In the fourteenth century the people of Dubrovnik dug a moat in front of the Pile Gate, on the west side of the city. In the fifteenth century they did the same on the east side.

Entrance to the Old Town is through the Pile Gate on the west side, via a two-arch stone bridge and a wooden drawbridge. This stone bridge underwent numerous changes and transformations over the course of the centuries. The original bridge built by military engineer Giovanni da Siena between 1397



Pile Footbridge



Inner Footbridge

Czech Republic



Bridge over the Vltava
■ České Budějovice
■ 2005–2006
■ Structure of the year 2006, Czech Republic
■ Bridge of the year 2007, Czech Republic

This footbridge in České Budějovice connects the historic town centre with a new residential area. The bridge consists of a tied arch inclined to one side and anchored to a composite deck. The arch has a span length of 53.20 metres and a rise of 8.00 metres and is formed by a steel pipe; the suspenders are formed from I-shaped steel members. The deck is formed by two edge pipes mutually connected by a truss floor beam and a composite deck slab. The steel structure is supported by a short cantilever protruding from the end diaphragm. To resist bending moments, the diaphragms are supported by a pair of piles. The steel structure was assembled on temporary towers. When the towers were removed, the composite deck slab was cast.

The bridge was designed by Stráský, Hustý a partneři s.r.o. of Brno and built by JHP Mosty of Prague.

Main technical characteristics:

Arch bridge – length: 64.5 metres;
span length of the arch: 53.20 metres;
width between the railings: from 3.52 metres



Bridge over the Vltava





Photo: Gonzalo Humar

Arts Bridge (Pont des Arts), Paris



Photo: Gorazd Humar

The Bridge of Peace, Tbilisi

Great Britain



Postbridge

- **Devon**
- 13th century
- The deck slabs weigh up to 8 tonnes each
- Protected status since 1967

Text by Brian Duguid

The oldest surviving footbridges in the United Kingdom include "clapper bridges", a simple form of bridge constructed from massive stone slabs supported by stone masonry piers. The most famous examples include the Tarr Steps in Somerset, a 55-metre bridge of 17 spans that is believed to date from around 1100; and Postbridge in Devon, a three-span bridge dating from the thirteenth century.

The deck slabs at Postbridge are reported to weigh up to 8 tonnes each. These bridges still rank as significant engineering achievements given the limited means available at the time of construction. The bridges have remained in continuous use since they were built, carrying both foot and packhorse traffic.

Postbridge is recognised for its historic significance and has been listed as a protected historical monument since 1967.



Great Britain

Mathematical Bridge

- **Cambridge**
- 1749, rebuilt in 1866 and 1905
- Historic timber footbridge
- Spans 12 metres over the river Cam
- Very efficient use of timber

Text by Brian Duguid



Few historic timber footbridges have survived. The Mathematical Bridge, which spans 12 metres across the river Cam in the university town of Cambridge, originally dates from 1749. The current bridge is actually a reconstruction to the same design, the bridge having been completely rebuilt in 1866 and 1905.

The design, by William Etheridge, uses straight timbers arranged radially and tangentially to a circular arc, giving rise to the bridge's nickname. It has been suggested that this represents a highly efficient use of the timber, and it has also been used for the timber centring for a number of masonry arch bridges. However, there is little evidence to support this supposition, and many of the timbers in the bridge are likely to carry very little load.

Although the Mathematical Bridge in Cambridge is well known, there is an essentially identical, albeit smaller, bridge of the same type at Iffley Lock in Oxford, built in 1924.



Hungary



"Mayfly" footbridge over the river Tisza

- Szolnok
- August 2009 to January 2011
- Main span 120 metres
- Fitted with tuned mass dampers

*Text by: Pálossy Miklós / Pont-Terv Zrt,
Budapest, Hungary*

A new bridge for cyclists and pedestrians over the river Tisza in Hungary was opened to traffic in 2011. The "Tiszavirág" (Mayfly) bridge creates a new link for the city of Szolnok and seems destined to become an emblematic work of art for the city. As well as the design of the bridge itself, the design competition included the reconstruction of the urban square on the right bank and the adjoining green area on the left bank in order to make the bridge fully accessible to pedestrians, cyclists and disabled users. The design competition was won by a team consisting of bridge consultants Pont-Terv and architects ADU. The winning concept was a slender, elegant, splayed arch structure, which was intended to combine a dramatic visual impact with good functionality and economic construction.

The steel arch bridge has a main span of 120 metres composed of two tubular arches splayed outwards at 60° from the horizontal and a spatial truss deck girder suspended by tie-rods. The deck consists of a steel grid covered with composite planks of wood and resin, which is a maintenance-free material. The glass panels spaced regularly along the centre line give variety to the wide homogeneous surface.

The LED lighting consists of a dotted line of lamps on the outer side of the arches, and light beams for illuminating the inner side. The illumination of the deck is provided by LED lights embedded in the handrails.

Since dynamic behaviour is a key issue in the case of slender pedestrian bridges, in-depth aerodynamic studies were carried out and four tuned mass dampers were incorporated into the deck in order to reduce pedestrian-related vibrations.

Erection on site was carried out using two auxiliary supports in the river bed. Since its inauguration the bridge has become very popular in Szolnok, and serves as a venue for various events in the city.

Main technical characteristics:

Main span: 120 m
Length: 186 m (main steel river bridge)
Total length: 320 m (including RC approach bridges)
Width: 5 m
Structural steel: 380 t
Design: Pont-Terv Zrt/ ADU Architects
Construction: KÖZGÉP Zrt

"Mayfly" footbridge over the river Tisza



Italy

The Rialto Bridge



The Rialto Bridge

(Ponte Rialto)

- **Venice (Venezia)**
- 1591
- Probably the most recognisable footbridge in the world
- Widest footbridge in the world (22.1 metres)
- Public competition held for its construction

*Text by: Gorazd Humar
All photos: Gorazd Humar*

The Rialto Bridge is undoubtedly the king of Venice's bridges. It is an unmistakable icon of the beautiful lagoon city and at the same time the oldest of the four bridges that cross the Grand Canal, the city's main thoroughfare. It is 22.1 metres wide, making it the widest of Venice's 431 bridges. Another unique feature are the 24 little shops that line the bridge: two rows of them rising up in steps on one side and descending on the other.

The bridge has a rich and varied history, just like Venice itself. It was built in 1591, in the period of the city's greatest prosperity. Preparations for its construction took almost a century, beginning in 1503 when a design for a new bridge was drawn up after the previous wooden bridge was destroyed by fire. It was not until after 1550 that the plan to build a new bridge began to be taken more seriously. The city authorities held a public competition to choose a design. The committee responsible for the competition was presided over by the powerful and influential salt merchants' guild, who wanted new shops on the bridge from which to sell their salt. The public competition was one of the first in history for an important construction project of this kind, and perhaps the first ever held for the construction of a bridge. One of the conditions laid down for the design of the new bridge was that the Doge's ceremonial galley must be able to pass under it.

In 1588, after a long search for a suitable solution and numerous quarrels, construction of the new bridge was entrusted to the architect Antonio da Ponte, who designed a single-arch bridge to span the Grand Canal. The new bridge, built of white Istrian stone, was completed three years later. The biggest technical challenge was represented by the foundations of the main arch, which was squeezed between the houses on either bank of the canal. Using specially designed foundations of considerable width, Da Ponte skilfully transferred the horizontal forces generated by the arch structure into the ground via foundations supported by wooden piles.

In 1591 the Rialto Bridge was opened to traffic. The 24 stone-built shops placed on the bridge soon opened for business and a safe and broad route across Venice's main traffic artery, the Grand Canal, was thus created. Most importantly, with its single arch, the new bridge allowed boats to pass along the Grand Canal unimpeded. The Rialto Bridge is probably the most famous and most photographed bridge in the world.



Italy

Sea Bridge



All photos: Oskar Da Riz, courtesy Textus Edizioni.

Sea Bridge (Ponte del Mare)

■ Pescara

■ 2008 - 2009

■ Cable-stayed footbridge

■ Total length 466 metres,
main span 172 metres

■ Two separate lanes for bicyclists
and pedestrians

Jutting out towards the Adriatic sea, Pescara is a city rich in contrasts: on the one side, the sea and a mainly urban territory that face each other, on the other, the river with the same name, Pescara, that splits the urban fabric in two quarters which are distinct and diverse both from an architectural and from a social point of view. In this difference lies, the origin of the “Ponte del Mare” (Sea Bridge), conceived as an element which can facilitate the physical and cultural reconnection of two seemingly opposite realities, with a past which is rich in history and a future in constant growth. Designed by Walter Pichler, an architect from Bolzano, the work is the tangible expression of the desire to give unity back to the urban fabric of Pescara, recreating the continuity of its seafront. The bridge’s morphology comes from this desire, two pathways that lift up from their respective banks as one to meet, ideally, in a place of physical and social reconciliation, suspended above the river. In fact, two rows of cables branch off from a central pier to support and balance the bridge’s two separate lanes, the bicycle lane which is 4 metres wide and the pedestrian lane which is 3 metres wide, that near the two ends merge into a single 5 metres wide lane. In this way, the bridge recreates a sort of empty space in the air, rich in meaning, that enclosed between the two curvilinear lanes gives the work the symbolic value of a monument to peace and gateway to new cultural exchanges, like those recently developed by the countries that border the Adriatic Sea.

Client: Comune di Pescara / **Designers:** Walter Pichler – Mario De Miranda



Poland



Malt Island Footbridge over the river Odra

■ **Wrocław**

■ **2002**

■ **Footbridge to Malt Island**

The Malt Island Footbridge crosses one of the arms of the river Odra in the centre of the city of Wrocław. The footbridge connects the riverside promenade to Malt Island (Wyspa Słodowa). The structure consists of two reinforced concrete spans and a main span in the form of a braced steel arch.

Design: Mosty-Wrocław s.c., chief designer Jan Biliszcuk



Poland

Footbridge over the river Dunajec

■ **Sromowce Niżne**

■ **2006**

■ **Span 90 metres**

■ **Was the longest glued laminated timber bridge in the world when completed**



Spanning the river Dunajec, this cable-stayed footbridge links the village of Sromowce Niżne in Poland to the village of Červený Kláštor in Slovakia. The deck of the footbridge is suspended from a pylon consisting of steel tubes. The deck itself is a glued laminated timber structure. On completion in 2006, the bridge became the longest glued laminated timber bridge in the world, with a span of 90 metres.

Design: Mosty-Wrocław s.c., chief designer Jan Biliszcuk



Spain

Cable-stayed footbridge over the river Manzanares



Cable-stayed footbridge over the river Manzanares

- **Madrid**
- **2009**
- Footbridge crossing two carriageways
- Two curved and connected U-shaped footbridges
- Single pylon
- Main span 120 metres

The purpose of the footbridge is to connect the two banks of the Manzanares river. Although the river is not very wide, the footbridge has to cross the two carriageways of the M30 peripheral motorway, which run parallel to the river, one on each side (Fig. 1) and the landing space is reduced since two streets run parallel to the river on both sides. The conceptual design consists of two curved U-shaped bridges connected in the centre and supported by a single pylon located on one of the river banks by means of cable stays. The shape of the bridge is the result of all the mentioned constraints as well as of the need to respect the maximum grade permissible for disabled users. The design was produced with the help of a scale model. The main span measures 120 metres and the height of the pylon is 42 metres.

The deck is a 2.44-metre-wide steel trapezoidal closed box which is complemented by transverse beams and a tube to increase the structural width and, consequently, the horizontal moment of inertia. The cables are of the locked coil type with a maximum diameter of 40 mm which were prefabricated to their exact length before installation. The steel pylon has a circular cross-section with a diameter ranging from 1.5 metres at the base to 0.3 metres at the top.

The deck was built in segments in a steel workshop. It was erected on site and welded to provisional supports limiting the spans to approximately 25 metres. These operations had to be performed during the night to allow interruption of traffic along the M30 motorway.

Owner: Municipality of Madrid / **Design:** Carlos Fernández Casado S.L. (Spain)
Contractor: FCC (Spain) / **Steelwork:** Megusa (Spain) / **Cables:** Tensoteci (Italy)



Japan

Kintai Bridge



Kintai Bridge (Kintai-kyo)

■ Iwakuni, Yamaguchi Prefecture Spans the river Nishiki

■ 1673

■ Length 193.3 metres, main spans 35.1 metres, width 5 metres

■ 15th reconstruction completed in 2004

Text by M. Matsui

All photos: M. Matsui and Hirano

The Kintai Bridge is a unique bridge consisting of five wooden arches spanning the river Nishiki. The bridge was built in 1673 to link the town where Kikkawa Hiroie, the feudal lord, and upper-level samurai lived, and the town where mid-level and low-level samurai and merchants lived. The river Nishiki served as an outer moat for the lord's castle. Later, in the Edo period (from the early seventeenth century to the mid-nineteenth century), the common people came to enjoy peaceful everyday lives, and a bridge was built to be sturdy enough to withstand floods and provide a crossing between the two towns. To date the existing bridge has been repaired and reconstructed 15 times. Rebuilding the bridge has always been done locally. For this reason, the necessary skills and techniques have been passed down from generation to generation.

Original designer: Kikkawa Hiroie, first lord of the Iwakuni Domain (17th century)



Japan



All photos: M. Iso

Kokonoe "Dream" Suspension Bridge [Kokonoe "Yume" Otsurihashi]

■ Tano, Kokonoe, Kusu District,
Oita Prefecture

■ October 2006

■ Single span unstiffened
suspension bridge

■ Main span 390 metres, width
1.5 metres

■ The longest pedestrian
suspension bridge in Japan

Text by M. Iso

Photos: © Kawada Industries Inc.

With a main span of 390 metres, the Kokonoe "Dream" Suspension Bridge is the longest pedestrian suspension bridge in Japan, spanning the Naruko Gorge at a height of 173 metres.

Owner: Town of Kokonoe

Structural Designer: Kyodo Engineering Co. Ltd.

Constructor: Kawada Industries Inc.



Japan

Hama Mirai Walk Footbridge

■ Nishi, Yokohama, Kanagawa
Prefecture

■ 2008

■ two-span, continuous steel deck,
box girder (rigid frame) bridge

■ two spans of 47.9 and 40.7
metres, deck width 10.4 metres

■ 2011 JSCE Civil Engineering
Design Prize

Text by N. Kuroshima



All photos: N. Kuroshima

The Hama Mirai Walk Footbridge spans the river Katabira and links the Yokohama East Exit and Minato-Mirai 21 areas. The footbridge is a tube-shaped deck which allows breezes to flow through it while providing shelter from wind, rain, snow, etc. The bridge is the integration of functional and aesthetic values achieved through modern technology.

Owner: City of Yokohama / **Designers:** Nippon Engineering Consultants Co. Ltd., M+M Design Office, and Nakajima Tatsuoki Lighting Design Laboratory Inc. / **Structural designers:** Nippon Engineering Consultants Co. Ltd. and Kanabako Structural Engineers / **Constructors:** **Substructure:** Kajima Corp. and Iwaki Kogyo Co. Ltd. JV, **Superstructure:** Yokogawa Bridge Corp., **Shelter:** Tsuboi Corp., **Lighting:** Kouyo Electric Equipment Co. Ltd., **Deck:** Techno-Japan Co. Ltd.





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