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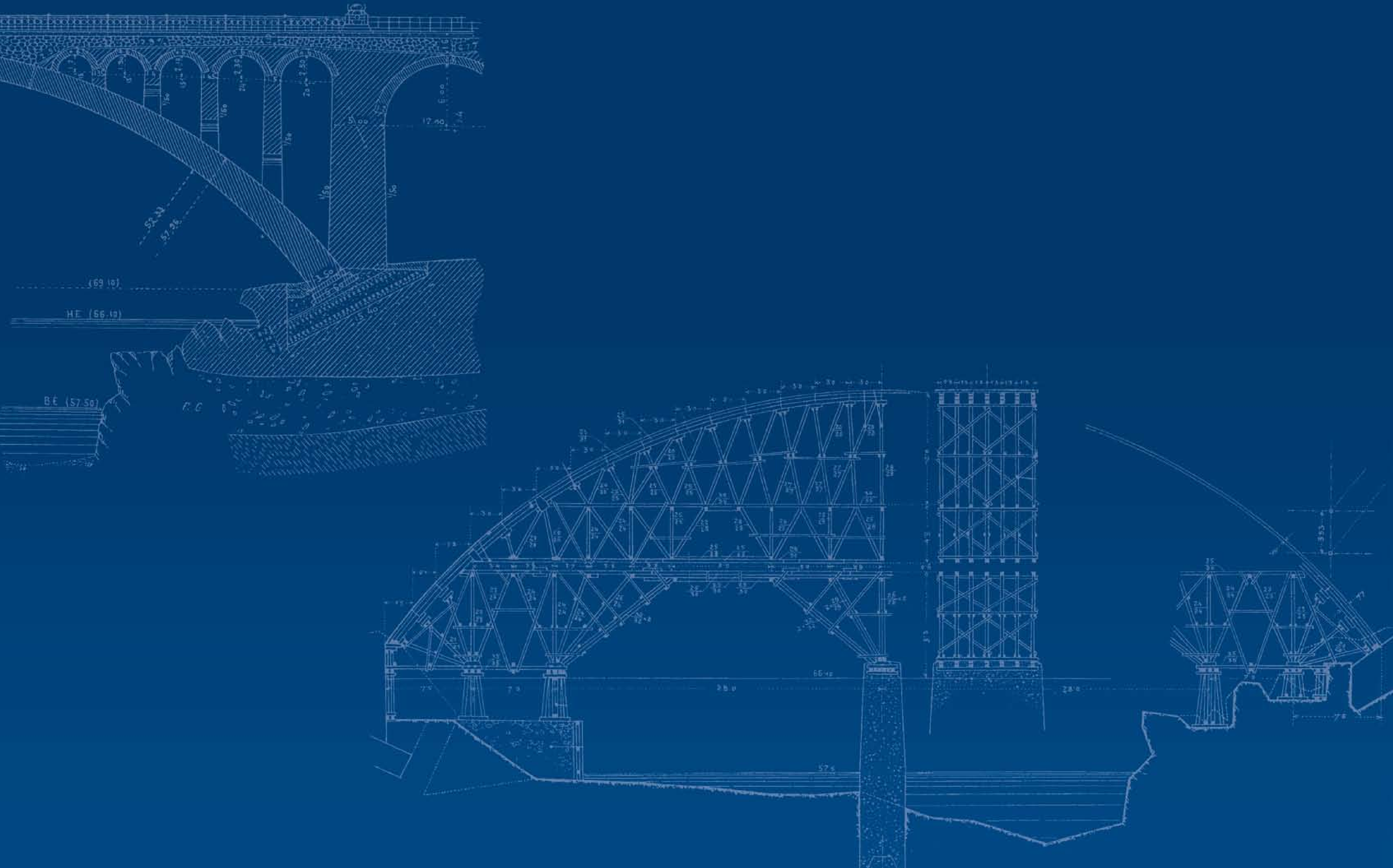
Civil Engineering Heritage in Europe

European Council
of
Civil Engineers

Civil Engineering Heritage in Europe

18th – 21st Century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Civil Engineering Heritage in Europe

18th – 21st Century

ECCE - 2009

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Civil engineering plays an important role in society and, in particular, in the protection of cultural heritage.

Vassilis P. Economopoulos
ECCE President*

Restoration of Acropolis
Athens, Greece

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* Elected for the period Oct. 2008 - Oct. 2010

ECCE President's introduction

A **Civil Engineer** is considered to be a person possessing the skills and the knowledge to combine analytical and synthetic approaches for detecting problems to find and to apply reliable, safe, economical solutions that are environmentally and socially acceptable solutions. From this point of view, a civil engineer is a producer, as well as a decision-maker.

A **Civil Engineer** is a designer, a constructor, a producer, a supervisor and a LEADER of integrated projects that increase the QUALITY OF LIFE OF HUMANITY.

A **Civil Engineer** acts as a professional within a framework strong moral and ethical standards seeking sustainable development and the protection of the natural environment, using construction activities compatible with a modern and viable urban environment.

CIVIL ENGINEERS SERVE THE PUBLIC INTEREST AND THE NEEDS OF HUMANITY.

We can refer indicatively to the work and to the impacts of the "public interest character" of our profession: protection and preservation of human cultural heritage, safety and quality of building constructions, earthquake protection, safety of dams, quality of life with an adequate water supply, quality of life through sustainable transport, quality of life and environmental protection with upgraded and innovative sewage and waste-water treatment plants, spatial planning for a sustainable urban environment, water resource management, renewable energy resources, energy efficiency of buildings, road safety, public transport infrastructure for sustainable cities, development of railway and highway infrastructure, connecting people, enhancing sustainable development, advancing public health with improved sanitary and social infrastructure, etc.

The European Council of Civil Engineers (ECCE) represents civil engineers in Europe via their professional organisations/associations in 24 States. It was established in 1985 and has since undertaken over 20 years of international activity on professional, education and training, research and technology, environmental protection and improvement, and sustainable development matters. The modern profile of the civil engineer to meet the society's needs requires a) knowledge b) skills and c) attitudes. In the national and international engineering Organisations, we must try continuously to achieve the highest level of quality of the educational background and professional skills/pre-requisites, as well as personal professional attitudes, to ensure the highest level of engineering service is provided.

Photo: courtesy of Freyssinet

You have in your hands a valuable "panorama" of the civil engineering heritage in Europe as symbolic thanks to all the creators of these important, critical and vital contributions to the world and to European society. Many thanks and congratulations to the ECCE family (the Editorial Board of the Book, the General Assembly of National Delegates, the Executive Board, standing committees and task forces) for their work in producing this book.

August 2009

Vassilis P. Economopoulos, M.Sc. Civ.Eng. NTUA
ECCE President

Editor's foreword

The idea of a book on Europe's civil engineering heritage was actually put forward some years ago by our Greek colleague Nick Zygouris, although considerable time would have to pass before it crystallised. The first thing we had to do was to set the criteria on the basis of which it would be possible to collect together, in the clearest possible manner, the full wealth and inventiveness of man's engineering skill in the sphere of important structures such as bridges, tunnels, roads and railways, dams, high-rise buildings and so on. The end results of our efforts are presented in this book, which takes us on a journey through the last three centuries of civil engineering in Europe.

Why does the book only cover this period of the rich and multi-millennial history of construction? Because it is only since the 18th century that we can talk about the formation of the first schools of engineering in France and England, about engineering as an approach to construction, and about the application of engineering knowledge in the creation of built structures. This is the period in which important traffic routes began to appear, and with them numerous bridges and tunnels. This is also the time in which civil engineering separated from architecture. The arrival and rapid development of the railway in the first half of the 19th century, shortly followed by the Industrial Revolution, gave civil engineering the impetus that propelled it with lightning rapidity through the 20th century and carried the discipline forward to its present state of development.

This book also tries to offer a balanced look at the development of civil engineering throughout this period in the ECCE (European Council of Civil Engineers) member states that have taken part in the project. The development of civil engineering has not been the same in every country in Europe, and not every country can boast structures of equal size and importance. But even the smaller countries of Europe have made their own contribution to the development of engineering knowledge in construction.

Although this book is not the work of professionals, the ECCE, as publisher, nevertheless set high criteria regarding content and quality. It has not always been possible to meet these criteria in full, since the articles and photographs that make up the book are the work of different authors and photographers, each of whom followed the aims of the project and the contextual framework of the book in a different way. Unfortunately the book does not include an overview of civil engineering achievements in every country in Europe. The fact that some countries have not participated in the project does not, however, diminish the importance of this book, which offers a good, clear overview of the development of civil engineering in Europe over the last three centuries. It is practically impossible to prevent knowledge and technologies from spreading throughout the world, since both are common and universal human categories that know no borders.

ECCE Editorial board: Nick Zygouris - Greece, Gorazd Humar and Branko Zadnik - Slovenia

The ultimate aim of this extensive project is the promotion of European civil engineering both in Europe and in the world at large, and the consolidation of the position of civil engineering in society and in the professional sphere.

August 2009

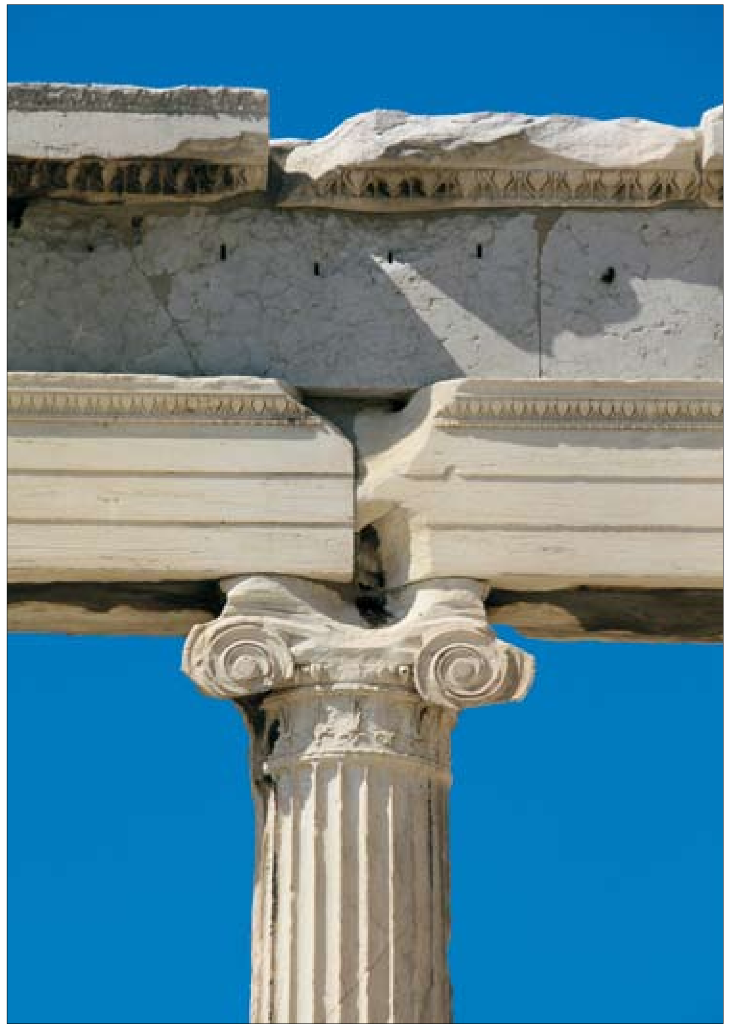
Gorazd Humar, B.Sc.C.E.
Editor -in-chief

ACKNOWLEDGEMENTS

Special thanks are due to current ECCE President Vassilis P. Economopoulos and the two Past Presidents Yrjö Matikainen and Richard Coackley for their extremely valuable help and cooperation in this important project.

We would also like to thank all the members of the ECCE Civil Engineering Heritage Task Force for their fruitful collaboration and all other representatives of ECCE Member Organisations who have helped to create this book.

On behalf of the Editorial Board – Gorazd Humar



Engineering is the bridge between Science and Society, turning scientific breakthroughs into practical tools for the wellfare of mankind.

José Medem Sanjuan
former ECCE President

Expressed during WFEO General Assembly, Moscow, Sept. 2001

A stroll through the history of civil engineering

Written by Gorazd Humar, B.Sc.C.E

This text is not, nor could it be, a comprehensive account of the history of the development of construction. Rather, it is a stroll through some of the important and epoch-making segments of the development of civil engineering in the last few centuries. It would be impossible to include in such a brief account all the inventiveness and the wealth of human genius that has brought the art of building and construction to all the stages of knowledge we have at our disposal today.

The important thing is that we learn from the experiences of the past and are able to prepare ourselves for the challenges of the future.

PRÆTERITI FIDES, SPES FUTURI
Latin proverb

Respect the past, believe in the future.

Stone was the dominant construction material for millennia

Greek temple, Agora, Athens.

The oldest building materials, most frequently used by humankind from prehistoric times onwards, were without a doubt wood and stone. Wood was popular and practical thanks to the possibility of working it, above all by chopping and sawing, while stone represented a more solid and durable construction material. By making better and more solid tools, particularly from iron, man was able to give stone any shape he desired. How else can we imagine the construction of the great sphinxes and pyramids in ancient Egypt four thousand years ago? Stone also proved itself to be the most suitable material for the building of temples, amphitheatres and other monumental buildings in ancient Greece. Stone was particularly useful for building bridges, especially those whose supports stood in fast-flowing waters.

It is difficult to say when the first stone bridges appeared. It was certainly several thousand years ago. Bridge constructions only developed slowly from extremely primitive forms, and it was only in the first millennium BC that the Etruscans developed the arch as a supporting construction element which soon found its place in bridge-building too. The arch construction proved so successful that it was soon being used by builders everywhere - in the Apennine peninsula, Persia, Mesopotamia, Greece and elsewhere. The oldest stone bridge still surviving today was built in Persia in the 4th century BC, the period of the Sasanid civilisation. The bridge, which is 600 metres long, had pointed arches.

The Romans were true masters of arch construction

The true round arch was not introduced into bridge and other constructions by the Romans, who developed this type of supporting construction to perfection both in terms of form and structure. Roman arch constructions (the arch usually took the form of a perfect semicircle) were built from hewn or carved stone in such a precise fashion that the stones fitted together without any form of mortar. This is the reason that most Roman bridges have survived to the present day. We are perfectly justified in saying that because of their solidity and durability Roman bridges allowed the Roman Empire to expand in all directions.

The bridge on the River Tajo at Alcántara in Spain commissioned by the Emperor Trajan in AD 104. It was built by Caius Julius Lacer and has the largest span of any surviving Roman bridge.

Today many well-preserved stone bridges and aqueducts built by the Ancient Romans can be found more or less all over Europe and even beyond it. Among the most beautiful of these structures is a group of stone arch bridges in the centre of Rome itself. These include the Fabricius bridge (Ponte Fabricio) and Cestius bridge (Ponte Cestio), which lead to the Isola Tiberina (an island in the middle of the Tiber), the nearby remains of the Palatine bridge (today known as the Ponte Rotto or Broken Bridge) and the still well-preserved Sixtus bridge (Ponte Sisto), and what is probably the most famous of Rome's bridges, the Ponte Sant'Angelo which leads to the Castel Sant'Angelo. This last, which in Roman times was known as the Pons Aelius, was built by the Emperor Hadrian between 133 and 134 AD. Another interesting bridge is the Milvius bridge (Ponte Milvio) which lies across the Tiber at the northern edge of Rome.

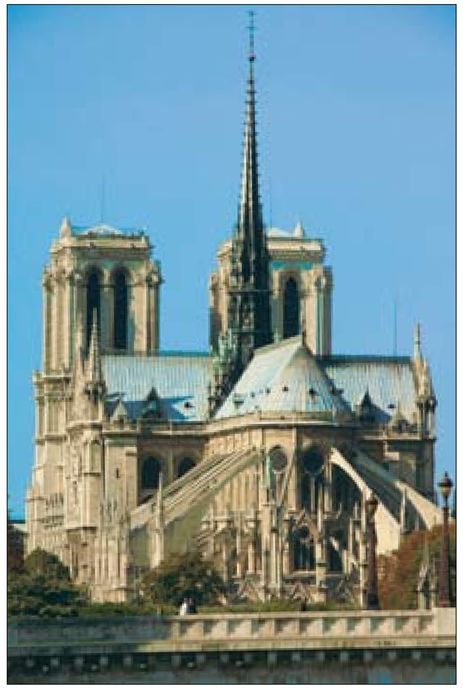
In 109 BC the Pons Milvius (Ponte Milvio) stood alongside the ancient Roman Flaminian Way (Via Flaminia). It was built by Marcus Emilius Scaurus at a point where a busy traffic route had passed several centuries earlier. It was later repaired and added to several times, though the arches of the bridge conserved their original semicircular form.

Among the best-known structures in Europe dating from the Ancient Roman period, aside from the bridges in Rome, are the bridges at Rimini in Italy and at Alcantara and Merida in Spain. Famous aqueducts include those at Segovia in Spain, Cologne in Germany and Split in Croatia, to name but a few.

The revival of construction development in the Middle Ages

With the fall of the Roman Empire the construction of solid stone bridges died away almost entirely for some centuries. We know of almost no important bridges built between the 4th and 12th centuries. This period was of course in general one of the darkest period of human history.

The next important advances in construction came in the Gothic period, which gave us some interesting bridges and cathedrals that were both daring and picturesque. The arch construction (characteristically pointed) again became the most important supporting element in building.



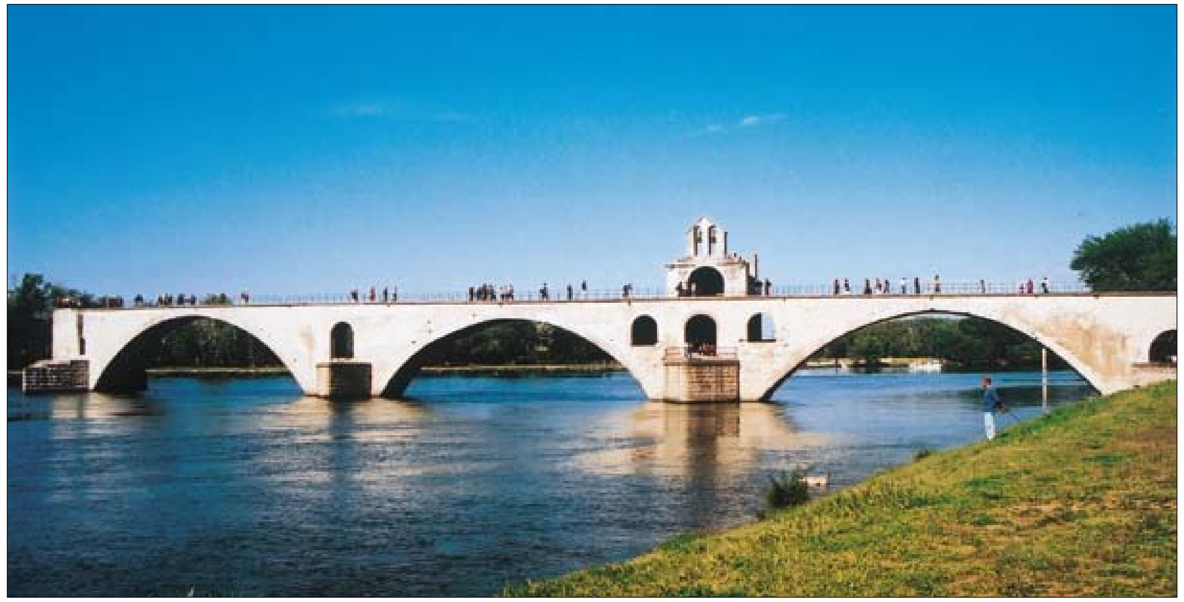
The cathedral of Notre Dame de Paris is an extraordinarily beautiful example of Gothic architecture, with elegant and slender flying buttresses supporting the nave. Construction began in 1163 and continued for two centuries.

It is interesting to look in more detail at how the supporting structure of Paris's famous cathedral of Notre Dame is constructed. The structure of the tall and slender nave with its characteristic pointed arches in the Gothic style does not differ significantly in the static sense from an arch bridge structure. The internal forces that formed within the main arch structure of the church roof were very skilfully, efficiently and almost unnoticeably transmitted to the ground via the numerous slender external ribs that take the place of buttresses. The supporting structure of such a large church as Notre Dame consists of numerous concealed arches which more than anything else resemble elegant bridge structures.

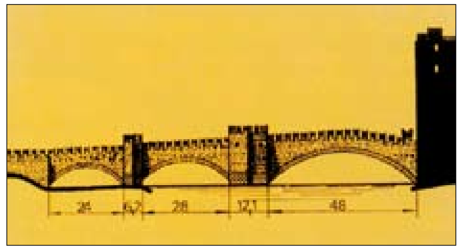
Throughout the second millennium France has been a country of large and beautiful bridges. The bridges that appeared in France have left a decisive mark on all later bridges. Who does not know the famous bridge at Avignon on the River Rhône, built in the 12th century (1177-1185) by friars of the order of St Bénèzet ('Frères pontiffs'). A special feature of this bridge is that it had what was, for the time, a very flat arch. Its builders used, for the first time, an arch whose curve was polycentric (made of three curves with different radii). The shape of the arch was very flat and differed significantly from the typically semicircular Roman arch still being used at that time.

The remains of the Avignon bridge are still standing today, though only four arches remain. The bridge was partially demolished in 1385 at the orders of Pope Boniface IX for defence reasons. The longest arch of the Avignon bridge had a span of 34.8 metres and a width of 8 metres. One special feature of the bridge is the chapel built on one of the piers, which in its day also served as a sentry box.

An outstanding bridge from the early Middle Ages is the Ponte Scaligero (or Ponte Vecchio) which crosses the River Adige at Verona. When it was built, in 1354-56, this bridge boasted the largest arch in the world (48.7 metres). Like the bridge at Avignon, the Ponte Scaligero already clearly indicated the tendency towards a flat arch as the main load-bearing structure. Like most other bridges built in the Middle Ages, the bridge had a defensive tower and several guard posts, while the parapet featured breastworks at regular intervals, another typical feature of the time.

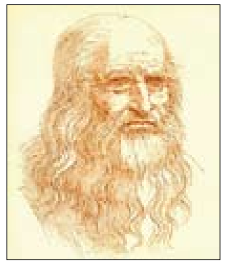


Bridge at Avignon, France (1177-1185). This bridge is notable for its very flat arches.

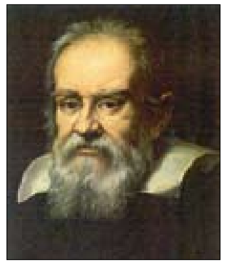


Ponte Scaligero in Verona, also known as the Ponte Vecchio. Built between 1354 and 1356, at the time of its construction it boasted the longest span in the world (48.70 m).

The rapid development in science during the Renaissance period also saw the art of bridge-building turn from empirical methods to increasingly engineering-based approaches to construction. The Renaissance period was marked by great names such as Leonardo da Vinci (1452-1519) and Galileo Galilei (1564-1642), who both set down the basics of mechanics and the strength of materials.



Leonardo da Vinci (1452-1519)



Galileo Galilei (1564-1642)

Particularly interesting among Renaissance bridges is the Ponte Santa Trinita in Florence. This bridge features very flat arches and an additionally curved form of transition from arch to piers. The form of the arches is strongly emphasised by archivolts (projecting edges at the front of the arch).

Among the great scientists of this period were Robert Hooke (1635-1703), the formulator of the theory of elasticity of material, and Isaac Newton (1642-1727) who laid the foundations of the law of gravity and thus also the foundations of modern sciences of the mechanics of materials. In a work entitled Principia mathematica philosophie naturalis, published in 1687, he presented the public with the three fundamental laws of motion that are the basis of today's dynamics of materials. The first law, which he derived from Galileo's principle, states that bodies move uniformly in a straight line provide they do not encounter any obstacle or friction. Newton's second law states that force is equal to mass times acceleration, while the third law states that every action has an equal and opposite reaction.

The Ponte Santa Trinità in Florence, with an unusually flat arch for the Middle Ages.

Many other great mathematicians and physicists contributed to the rapid development of engineering science in the 17th century and also provided the theoretical basis for the development of true engineering science in the construction of bridges.

The beginning of the 18th century was the period of the Enlightenment (the century of light - siécle de lumière) in France and in most other countries of Europe. The Enlightenment started as a resistance to the bloody religious wars that sapped the economic strength of the Europe of the time. Linked to philosophical ideas about the liberation of man from religious hegemony, the Enlightenment made an important contribution to the development of science in the 18th century.

Isaac Newton (1642-1727), the father of modern physics and mathematics.

Jean Rodolphe Perronet (1708-1794) introduces revolutionary innovations into bridge-building

Jean Rodolphe Perronet (1708-1794), director of the first engineering school in the world, the École des Ponts et Chaussées, founded in Paris in 1747.

In 1716, as a result of the growing need for bridges, the first military engineering school (Le corpes des ingénieurs des Ponts et Chaussées) appeared in France. An even more important event which was to prove decisive for the development of modern bridge-building was the founding of the famous French engineering school known as the École des Ponts (today École Nationale des Ponts et Chaussées). This school was established in 1747 by the decree of Louis XV, though its true founder was Daniel Trudaine, the king's financial manager. On 14 February 1747, the day the famous school was founded, Jean Rodolphe Perronet became its director or first engineer, remaining in this post until his death in 1794. Over the course of his 47 years of running the school Perronet laid the foundations of modern engineering science in bridge-building and introduced pedagogical methods in the teaching of the science of bridge-building.

There is an interesting story about how Perronet became the first director of the École des Ponts (School of Bridges). One day, when he was a little boy, he was playing in the gardens of the Tuileries. The young prince, later to be King Louis XV, came up to him and invited him to play with him. Out of this game a friendship was born between them, which later helped Perronet to be appointed the director of the first bridge-engineering school in the world.

Primarily, however, Jean Rodolphe Perronet wrote himself into history and the list of eminent bridge-builders through the revolutionary changes he introduced to bridge constructions. Many famous bridge-builders have even called him one of the greatest engineering geniuses the world has ever known.

Where does the greatness of his work lie? Perronet made a decisive move towards a different way of thinking about the dynamics of the arch as the main bridge construction. This demonstrated above all by the fact that he reduced considerably the height of the arch and thus also flattened the arch, while at the same time reducing its thickness. This change in the form of the arch was most notable in the Saint-Maxence Bridge (1774) over the River Oise, where the compression of the arch was in what even for today's conditions an exceptional ratio of 1:12 (the ration between the height and span of the arch).

Perronet's plan for the Pont de la Concorde in Paris, built between 1787 and 1791.

The Pont de la Concorde is still one of Paris's main bridges.

Perronet's most famous bridge is the Pont de Neuilly on the River Seine, built in 1770-72, which sadly is no longer standing. In this bridge Perronet's engineering knowledge really found expression. When it was built, this bridge was one of the most beautiful in the world. As well as flattening the arch, Perronet also reduced greatly the thickness of the supporting walls of the main piers of the bridge. He worked on the assumption that the intermediate piers tend only to support a vertical load because of the constant weight, while the effects of the horizontal forces caused by the traffic load are mainly borne by the more powerful abutment piers on the banks. This concept of reducing the thickness of the supporting piers and increasing the spans of the arches also contributed to greater water flow below bridges, a reduction in the costs involved in sinking piers into the water, a reduction in the erosion of piers, and an increase in the safety of vessels passing under bridges. While in the case of Roman bridges the ratio between the length of the arch and the thickness of the pier was 4:1, with Perronet's bridges it was 9:1.

Perronet's second most famous bridge is the stone Pont de la Concorde in Paris, built in 1787-91. The plan which Perronet showed to the authorities envisaged an arch with a span (l) of 31.2 metres and a height (f) of 2.77 metres, which gave a compression ratio of l:f = 31.2 m : 2.77 m and a factor of m = 11.20. The plan had already been approved by King Louis XV, but the authorities were alarmed by the boldness of the arch design and the minister of public works requested that the height of the arch be increased to 3.97 metres, giving a compression ratio of l:f = 8. Perronet also had to increase the thickness of the supporting piers, thus making them more massive. Naturally Perronet was greatly affected by this interference of the authorities in the area of bridge planning. He responded to the pressure by redesigning the bridge's parapet. Because of the enforced change in form caused by increasing the height of the arches he improved the visual slenderness of the arches by making the parapet a balustrade rather than a solid wall. In this way he increased the airiness of the bridge construction and through an optical trick increased the slenderness of the arches.

The invention of the steam engine and the building of the first railway

Richard Trevithick (1771-1833), the undoubted inventor of the steam locomotive

George Stephenson (1781-1848)

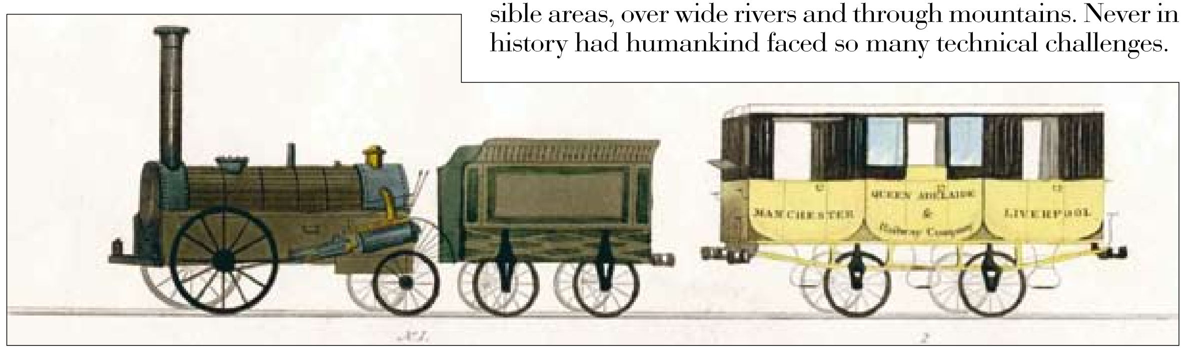
Few inventions have so thoroughly changed the course of human history as did the invention of the steam engine. This invention radically changed the development of technology and, consequently, the construction industry and many other areas of human activity. With steam engines such as those that Scottish engineer James Watt (1736–1819) began producing on a regular basis in 1774, industry entered an undreamt-of period of development. Initially somewhat clumsy and not yet very powerful, the steam engine slowly established itself in many fields of industry. From driving pumps in mines, the job for which the steam engine was first built, its use spread to means of transport, and it was not long before attempts were made to fit a steam engine to a vehicle running on rails. Richard Trevithick built the first locomotive in 1804. A new era had begun – the era of the industrial revolution, which was further enhanced by the introduction in 1830 of steam locomotion on the Liverpool–Manchester railway line.

The first public railway, built by George Stephenson (1781–1848), actually began operating between the towns of Stockton and Darlington in England in 1825, but initially horses were still used to pull the wagons along the rails – until a steam locomotive known as the Active (later renamed Locomotion No 1) began to run on the line. Stephenson and his son Robert (1803–1859) built their own freight locomotive. In 1829 their locomotive Rocket won the trials held to choose a locomotive for use on the Liverpool–Manchester railway, and this contributed to the exclusive use of steam power on that line.

The era of rapid progress in the development of railways had thus begun. The railway network began to spread across Europe like drops of oil on the surface of the water. By the middle of the 19th century railways had reached practically every country in Europe.

The development of the railways brought with it the rapid development of the construction industry. We might also say it was the other way around: the high level of development of construction engineering in the first half of the 19th century, and in particular the techniques used to build bridges, viaducts and tunnels, enabled the railway to reach even inaccessible areas, over wide rivers and through mountains. Never in history had humankind faced so many technical challenges.

The train that ran between Manchester and Liverpool.



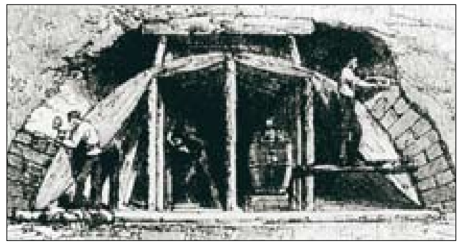
A brief look at tunnel-building in the 19th century

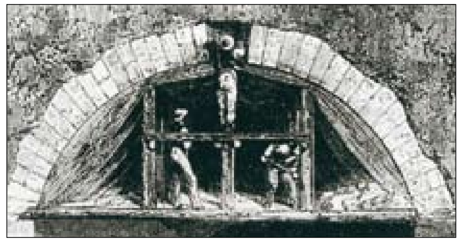
A real turning-point in the construction of tunnels occurred at the start of the 19th century with the building of the tunnel on the St Quentin canal in France (built 1803). During construction of this tunnel in sandy ground, which caused great internal pressures, the builders encountered for the first time the serious problem of supporting tunnels during excavation. A system of props like those used in mines was employed during the building of this tunnel, which was 110 metres long and 8 metres wide, and a method known as the 'core method' was adopted. This involved driving a series of smaller tunnels or drifts in the line of the perimeter of main tunnel, lining the tunnel as the digging progressed, while the inner core of the unexcavated section of the tunnel remained untouched until the perimeter was fully supported and under its protection it was possible to excavate the core of the tunnel. The solutions adopted in the construction of this tunnel laid down the first modern guidelines for the building of new tunnels in the 19th century, a period in which tunnel-building experienced rapid and unimagined development. In France alone, twenty tunnels with a total length of 28,500 metres were built on canals in the first half of the 19th century.

In 1842 the French engineer Henry Darcy (1803–1858) used a similar technique (the core method) to build an important tunnel to supply water to the city of Dijon in Burgundy. Darcy is considered the father of modern underground hydraulics. He is still mentioned in numerous technical works today.

The first serious attempt at digging a tunnel under water was made in London at the beginning of the 19th century, with the attempt to build a road tunnel beneath the Thames.

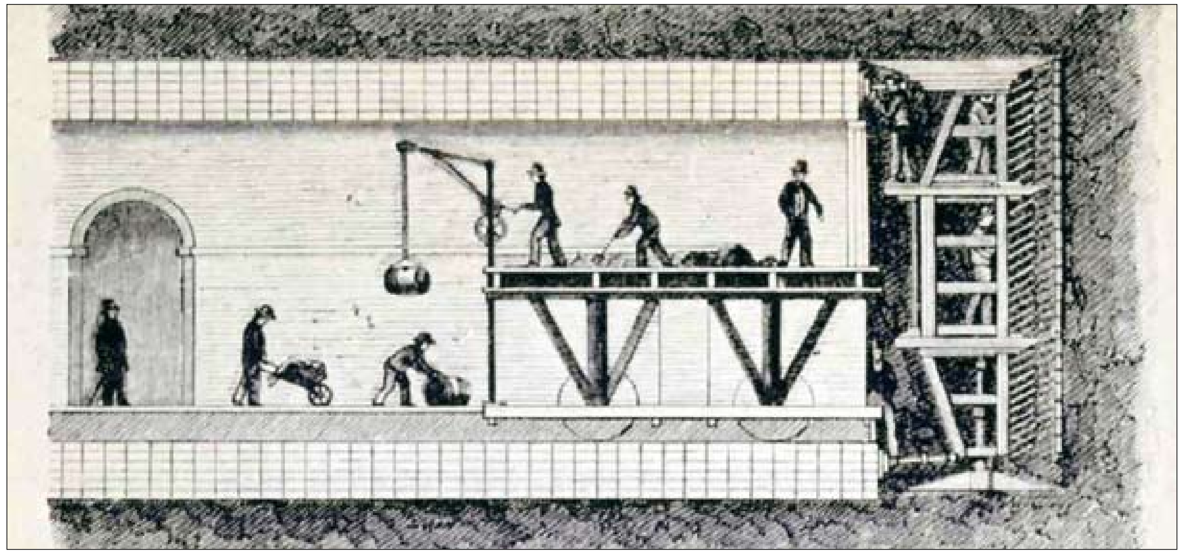
Work was begun by Richard Trevithick (1771–1833), who began driving a small probe tunnel. On 26 January 1808,





Construction of the Blaisy Tunnel in Burgundy, France, to the design of the engineer Henry Darcy.

The method devised by the English engineer Marc Isambard Brunel to dig a tunnel beneath the Thames in London in the first half of the 19th century.



Isambard Kingdom Brunel (1806-1859)

Flood in the Thames tunnel in 1826.

A modern tunnel boring machine (TBM), as used in 2001 to bore the water tunnel for the Plave hydroelectric plant in Slovenia.

after the tunnel had progressed 333 metres, there was a sudden inrush of water at high tide and the tunnel workers and Trevithick himself, up to his neck in water, were lucky to escape with their lives.

As a result, the Thames Archway Company decided to abandon the project. Work on the Thames tunnel did not resume until 1823, when the engineer Marc Isambard Brunel (1769–1849) made a new attempt at excavating a tunnel at a greater depth below the bed of the Thames. After several instances of flooding and 18 years of work, the tunnel was completed in 1841 by his son Isambard Kingdom Brunel (1806–1859), one of the greatest British engineers of the 19th century, who himself nearly lost his life during construction of the Thames tunnel.

A more detailed study of the method used to dig the tunnel beneath the Thames in London makes stirring reading.

For centuries engineers and miners had struggled with the problem of how to dig tunnels in very soft ground and with the danger of influxes of water and mud. The first to address this problem seriously was Marc Isambard Brunel.

Owing to the numerous difficulties caused by influxes of water and mud while digging the tunnel beneath the River Thames in London (1825–1842), Marc Isambard Brunel came up with the idea of an iron shield with a rectangular cross-section which would allow the workers to dig the tunnel in safety. The front of the protective shield contained a number of apertures through which the men excavated the tunnel face. As the tunnel progressed, the shield was moved forward by means of screw jacks supported by the brick-lined wall of the tunnel. From the mechanical point of view this is very similar to the method used today to move a tunnel boring machine (TBM) forward by means of hydraulic jacks.

Not only that, but the method of transport and removal of material from the tunnel was also very similar to the excavation method using modern rotating TBMs. This is why rather more space is dedicated in this book to the excavation of this tunnel (see the section on the United Kingdom). This achievement set new markers in tunnel-building worldwide.

The first man to build a cylindrical tunnelling shield was the British engineer Peter W. Barlow of London. In 1865 he built a shield with a diameter of 2.5 metres which was used to drive a small tunnel under the Thames. The effectiveness of using a tunnelling shield became apparent in the unexpectedly low excavation costs. At about the same time the American engineer Alfred Ely Beach was using a similar method to dig tunnels in New York. In 1880 the British engineer James Henry Greathead successfully used compressed air inside a tunnelling shield to prevent the influx of water. At the end of the 19th century the combination of an iron tunnelling shield and compressed air enabled tunnels to be built under rivers.

Modern tunnel boring machines are similar in their essential principle to the device developed by Greathead. The only difference was that in the 19th century the rotary boring machine inside an iron shield had not yet been invented.

No less important, owing to the introduction of a new method of excavation, was the construction of the Pouilly Tunnel on the Canal de Bourgogne in France (1842). A method of supporting the roof with the help of longitudinal supporting elements and props arranged in a fan shape and resting on a core in the centre of the tunnel was used for the first time in the building of this tunnel. Almost simultaneously, the Riqueval Tunnel was built on the St Quentin Canal. Measuring 5,670 metres, it was for a long time the longest tunnel in the world.

England did not lag behind in the construction of water tunnels in the 19th century, and by the middle of the century more than 45 had been built, with a total length of 67,100 metres.

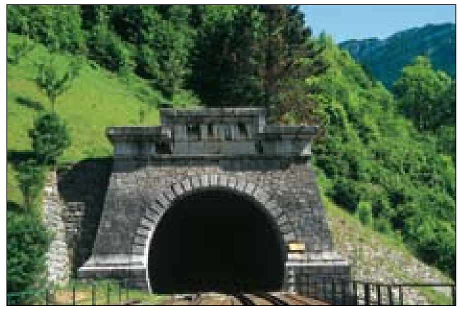
The first large road tunnels were built in the Alps. In 1707 the 64-metre Urner Joch Tunnel was built under the St Gotthard Pass. It was followed by the Mont Cenis Tunnel, the Simplon Tunnel and many others. All of these tunnels were built in solid rock and without supports.

The breakthrough of the Brenner railway tunnel between Austria and Italy, second half of the 19th century.

Railway tunnels

The development of railway lines represented a brand-new era in tunnel-building. The first railway tunnel was built between 1826 and 1830 by George Stephenson, famous for his locomotives and railway lines, on the Liverpool–Manchester line.

Soon after this the railway network began to spread at incredible speed throughout Europe and the rest of the world. The necessarily small inclines on railway lines meant that it was not possible to overcome significant height differences. Tunnels and bridges were thus structures without which no important railway line could have been built. Many tunnels appeared in many European countries, and many different methods of tunnel-building were developed, named after the countries in which they were used. These include the Belgian method, the Italian method, the English method, the new and old Austrian methods, the German core method, and many others. These methods developed out of various engineering experiences and on the basis of the different characteristics of the rock found in the individual countries. Each method offered its own solutions to the various situations encountered by the builders.



The imposing mouth of the Bohinj railway tunnel (l = 6,327 m), Slovenia.

Tunnel-building know-how advanced rapidly in the 19th century and provided better and better solutions to the problems of support, ventilation, drainage etc. The biggest danger, besides the great pressures that tunnels had to withstand, was the presence of explosive gases, particularly methane, underground.

The practical use of compressed air and the ability to supply it through long tubes contributed to the development of the first automatic drilling machines used to bore the holes in which the explosives were placed. This method, first used by the Swiss engineer Daniel Colladon in 1852, was very success-

The first pneumatic drilling machine, invented in 1859 by Germain Sommeiller.

Alfred Nobel (1833-1896)

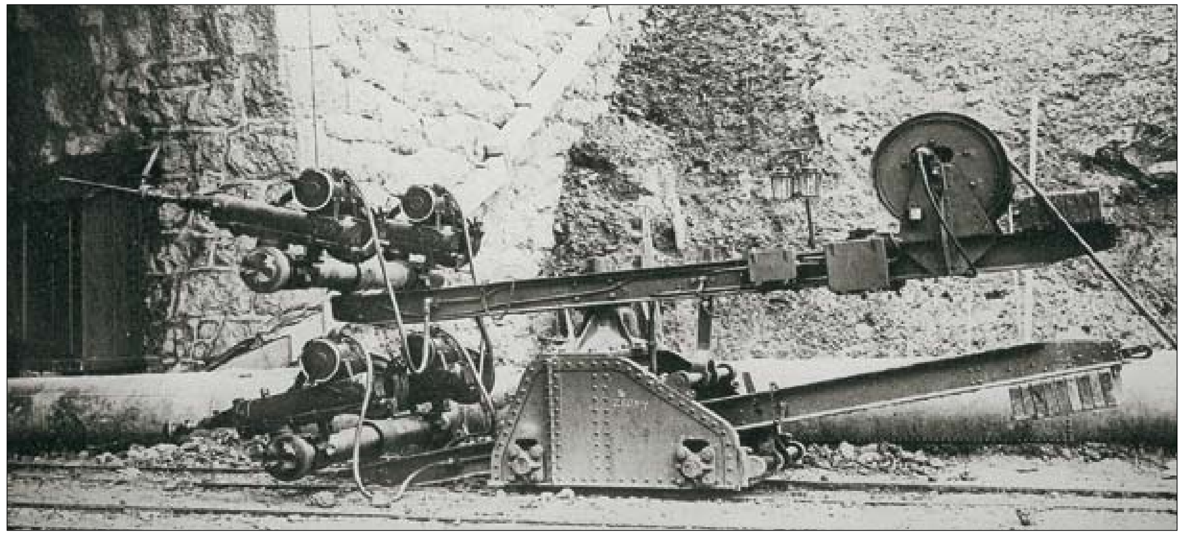
ful. Pneumatic drills were used in the building of the Mont Cenis (1854–1871) and St Gotthard (1872-1881) tunnels.

The first working pneumatic drilling machine was developed in 1859 by Germain Sommeiller, a civil engineer from Savoy. Its efficiency led to it being used to bore the 12,290-metre Mont Cenis tunnel. When work on the tunnel began in 1854 using the manual method, progress was just 0.60 metres a day. It looked as though the builders would never be able to tunnel through Mont Cenis. With the advent of the pneumatic drilling machine, the situation was turned on its head. The use of compressed air was so effective that it was even used to drive locomotives in this long tunnel.

Another important technical turning-point in tunnel-building came in 1875 with the use of dynamite as a means of blasting tunnels. Dynamite, invented in 1866 by Alfred Nobel (1833–1896) was first used instead of gunpowder, which at that time was still widely used in tunnelling works, in the building of the Gotthard Rail Tunnel between Switzerland and Italy. The tunnel is 14,998 metres long and it took 9 whole years to build (1872–1881). In the construction of a tunnel as long as this, the use of dynamite greatly increased the efficiency of the excavation. This was very evident from the speed at which the work progressed.

The Gotthard Rail Tunnel is unfortunately also famous for another, more tragic reason. During the building of this long tunnel (at 14,998 metres it was at that time the longest tunnel under construction anywhere in the world) around 200 workers lost their lives. Tragically, just 233 days before the breakthrough of the tunnel on (28 February 1880), the director of works Louis Favre died in the tunnel after suffering a heart attack. When, much later, a road tunnel of approximately the same length was built under St Gotthard using more modern techniques and supports, 19 workers died, which is 10 times fewer than in the building of the rail tunnel, although the number of deaths still exceeded the tragic ratio of one human casualty per kilometre of tunnel.

Siemens & Halske working platform with four electric drilling machine operating on three-phase current. First used to dig the Bohinj and Karavanke tunnels (Slovenia) in 1904, it was the most modern machine of its kind.



Underground railways/metros

Underground railways or metros are a characteristic feature of large cities, where they developed in the second half of the 19th century and the early 20th century in order to meet the needs of ever denser traffic and enable faster connections between the individual parts of a city. The construction of metros was aided by the already high level of technological development of railways and existing knowledge about building tunnels under rivers and buildings. Building tunnels for underground railways was of course different from building traditional railway tunnels. The main difficulties lay in the fact that metro tunnels had a relatively small covering of earth above them, and there was therefore a danger of earth, buildings and even rivers irrupting into them. For this reason the roofs of the first metro tunnels were supported by a large number of steel arches.

The first underground railway, the Metropolitan Railway, opened in London in 1863. It was soon followed by underground railways in Berlin (1871) and New York (1872). Vienna, the capital of the Austro-Hungarian Empire, got its first metro in 1894, while the first metro in Paris was not built until 1900 (the 10-kilometre Maillot-Vincennes line). In the early 20th century underground railways became vital transport arteries in many major European cities.

Typical metro station sign in Paris.

Construction of the Paris metro using iron arches (early 20th century)

Acropolis Metro Station under construction
Athens, Greece
(ATTIKO METRO SA/YPEXODE)

Iron bridges slowly establish themselves

Abraham Darby III (1750+1791)

Stone was for millennia the material most used in bridge-building. This was because of its durability and the possibilities it offered of various treatment. Man also built wooden bridges, but because of their limited lifespan few of these have survived to the present day.

At the end of the 18th century a new building material began to be used in bridge-building which before that time had been unable to reach a wider use. In 1779 the first iron bridge was built in England. This was the bridge across the Severn at Coalbrookdale, built by Abraham Darby III. The cast-iron arch bridge, which is still standing today, has a span of 30 metres. It is protected as a monument and serves as an open-air industrial museum.

Naturally the construction of steel bridges at this time was unable to develop more quickly because of the high price of iron and steel. Industrial blast furnaces were only introduced into ironworks at the end of the 18th century, which was also the period that the first cokeworks appeared. The first man to make coke from coal was Abraham Darby III, the builder of the iron bridge over the River Severn. It is no coincidence that the first iron bridge in the world appeared near the great ironworking centre of Coalbrookdale in England.

The first iron bridge in the world was built in 1779 over the River Severn at Coalbrookdale in England. The bridge, which has a span of 30 metres, is today a Grade I listed building and a scheduled monument and a very popular attraction.

In 1826 Thomas Telford shifts the boundaries of the possible

The ability to built simple suspension bridges goes far back into history. Man has always sought safe routes across wide rivers and valleys. Even today ingenious and authentic suspension bridge structures are most numerous in foothills of the Himalayas. But such structures could never be suitable for the heavier road freight of the kind that was becoming common in Europe in the early 19th century. The man who had gone furthest in the development and construction of large suspension bridges at that time was the American engineer James Finley, who in 1808 patented a system for building suspension bridges using wrought iron chains. He described the process in detail in 1810 in the New York periodical The Port Folio. But James Finley was not a particularly successful bridge-builder, and some of his bridges even collapsed.

The idea of bridging large spans, fortified by ever improving knowledge of the properties of iron, was one that particularly preoccupied Thomas Telford, already well established as an engineer in England. In 1800 the decision was made to build a replacement for the old London Bridge over the Thames. Telford proposed a bridge with a single arch spanning 183 metres. The arch would consist of several transversely interconnected iron arch supports. This project was never realised.

Thomas Telford did however develop his bold ideas in another direction. Emboldened by the idea of a large suspension bridge, in 1817 he began planning a new bridge over the Menai Strait in Wales. Constructed between 1819 and 1826, the new Menai Suspension Bridge was supported by wrought-iron cables. With a span of 176 metres between its towers, it transcended the boundaries of the possible and heralded a new era of construction of even bigger bridges. The bridge is probably Thomas Telford's greatest monument.

Thomas Telford (1757-1834), an eminent engineer and the founder of the Institution of Civil Engineers (ICE), still today the leading engineering institution in the United Kingdom.

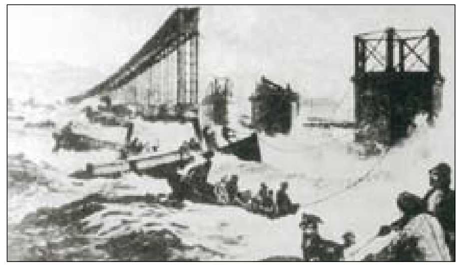
The bridge over the Menai Strait in Wales. Constructed between 1819 and 1827, it has a span of 176 metres.

The Chain Bridge in Budapest, Hungary. It was built between 1839 and 1849 and has a central span of 202.6 metres.

The development of suspension bridges was, however, advancing rapidly. In 1834 a suspension bridge with a span of 273 metres – a new world record for suspension bridges – was built at Fribourg in Switzerland.

Unlike Thomas Telford, who had used wrought-iron chain cables to build the Menai Bridge, the engineer Joseph Chaley used wire cables to build his bridge at Freibourg. The development of new, even bigger suspension bridges progressed ever faster from this moment on.

Steel enjoys its golden age in the second half of the 19th century



The Firth of Tay Bridge in Scotland, which collapsed on a stormy night in 1879. The accident claimed many lives.

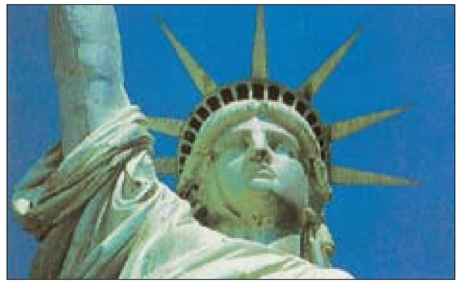
Steel only came into more widespread use in bridge-building more than a century after the construction of the first iron bridge. There were many abortive attempts at building steel bridges. Bridges collapsed either because the steel was not yet sufficiently good, because of construction errors, or because the limit properties of steel were not yet well enough known. In Britain the Tay Bridge disaster is still remembered with horror. On a stormy night in 1879, the bridge over the Firth of Tay (near Dundee in Scotland) collapsed as a train was passing over it. The train plunged into the murky depths of the river, taking many passengers with it.

This disaster shocked the world. It drew bridge-builders' attention to the fact that not enough was yet known about steel as a building material. Out of every misfortune, though, comes something good. Scientists plunged even more zealously into the study of the properties of steel and its possibilities of use. There was not long to wait for a response. Almost simultaneously three interesting large steel bridges appeared in three different parts of Europe.

Gustave Eiffel (1832-1923)

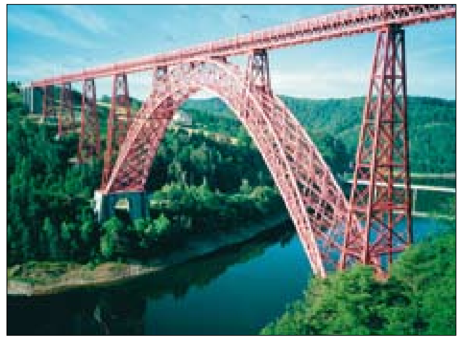
In 1884 the famous French construction engineer Gustave Eiffel built a large arch bridge over the River Trugère near the town of Garabit. This bridge, made of iron from which the carbon had been removed, had an arch span of 165 metres, the largest arch support of any bridge in the world at the time. Gustave Eiffel is of course better known as the builder of the 300-metre-high steel tower in Paris which bears his name (built in 1889). Perhaps we are doing this great bridge-builder an injustice when we think, whenever we hear his name, only of the eponymous tower which gives Paris its characteristic skyline and not of the fact that he was above all an engineer and a pioneer of the largest iron and steel bridges.

The great Statue of Liberty, New York



Another interesting point worth mentioning is that Gustave Eiffel was responsible for one other famous construction that dominates the skyline of another great city, in this case New York. The great Statue of Liberty, the symbol of longing for millions of immigrants from the Old World which stands before the entrance to New York harbour, is also the work of Gustave Eiffel.

The Garabit Viaduct, as Eiffel's great bridge is also known, was overtaken in terms of size by the bridge built in the Wupper valley near Müngsten in Germany in 1897. This bridge took the world record for steel arch bridges with an arch span of 180 metres.



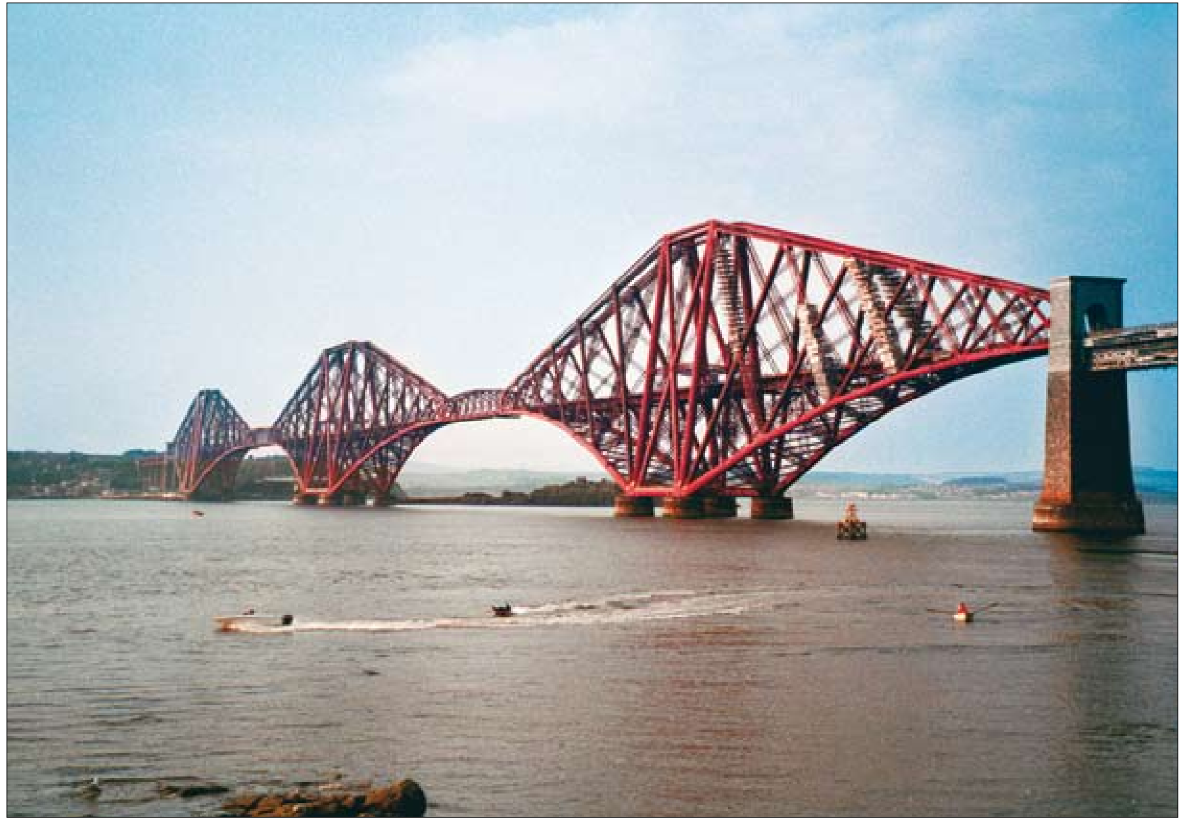
The Garabit Viaduct in France, one of the most famous iron bridges in the world, was built in 1884 by the engineer Gustave Eiffel. The principal arch has a span of 165 metres.

A list of great steel bridges would of course be incomplete without a mention of the Forth Rail Bridge built across the Firth of Forth near Edinburgh in Scotland in 1883-90. This truly mighty bridge, built to carry the railway, has two main load-bearing fields each 521 metres long, an almost inconceivable length at the time. The construction, whose spans were constructed as cantilevers extending from one pier towards the other and vice versa, demanded enormous effort from the builders, particularly when it came to building the foundations of the main supporting members in the water. The rough waters, which rose and fell by nearly seven metres with the changing tides, made it very difficult to construct the caissons used in laying the foundations. The bridge contains 54,000 tons of steel. During construction, which lasted seven years, 57 labourers lost their lives. Few bridges have claimed such a toll.

Even so, this magnificent bridge laid down new markers in the construction of large steel bridges. At the same time it symbolised the high level of industrial development of the United Kingdom at that time, as well as its engineering prowess.

The Forth Rail Bridge in Scotland, with two main spans measuring a record-breaking 521 metres. Forty-four workmen died during its construction. Built between 1883 and 1890.

Photo: Robert Cortright, USA

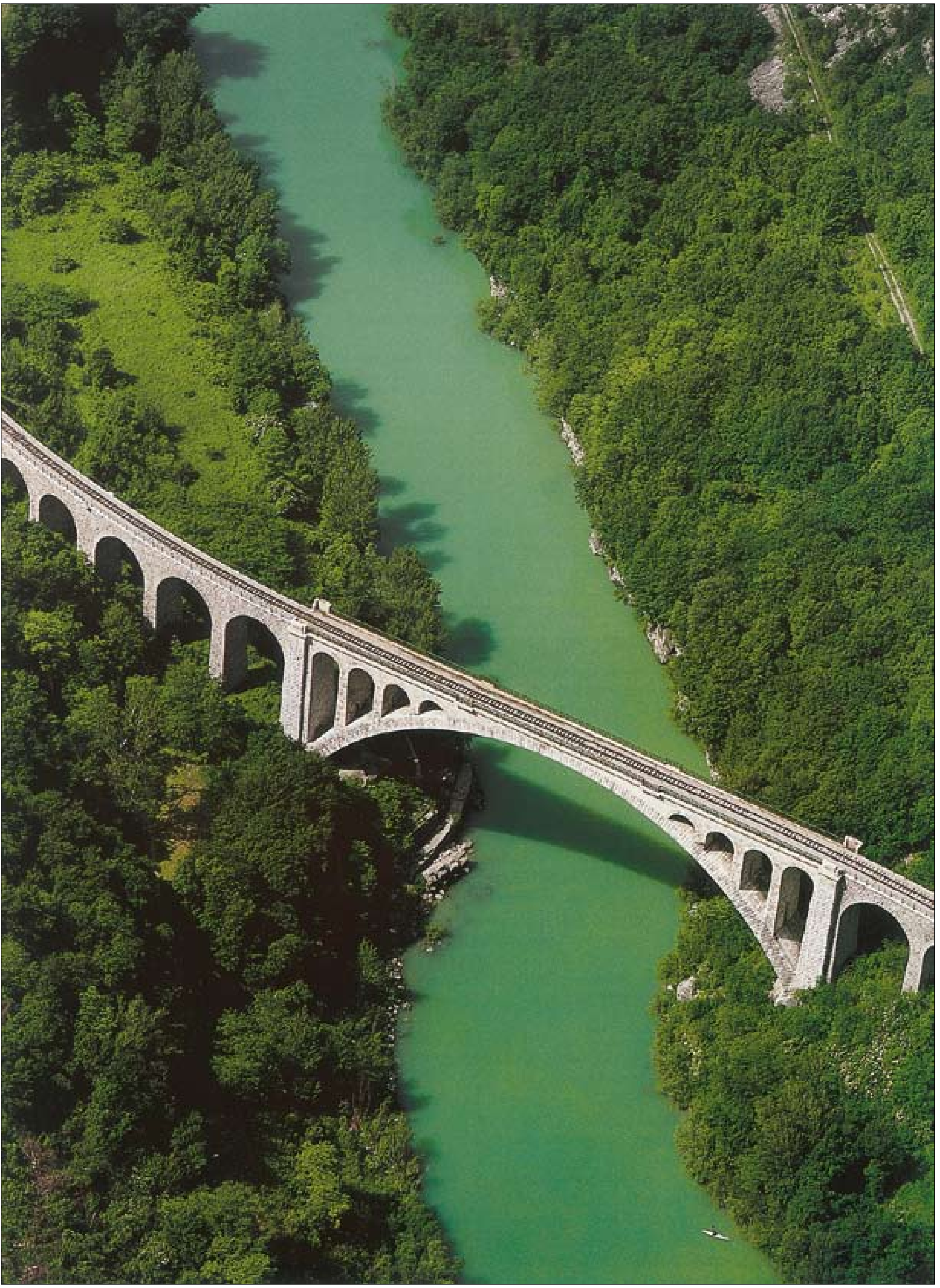


The twentieth century is the century of concrete bridges

Reinforced concrete is the building material that has left the greatest mark on human civilisation in the 20th century. Its rapid rise to prominence, after the timid and cautious steps of the first pioneers of reinforced concrete in the second half of the 19th century, has revealed limitless uses for what at first glance is a simply prepared material, though one which is still the object of study for countless researchers in the field of construction. No material in use today is the subject of so much attention, interwoven by the desire for the cheapest possible building material and the boldest possible constructions such as great bridges, tall skyscrapers and mighty dams. On the other hand a certain amount of resistance is appearing to this modern ‘grey and dreary’ material that accompanies almost our every step. Modern, environmentally conscious man would in fact like to escape from concrete but he is forced to use it by the desire for the greatest progress and comfort, the desire for modern traffic connections and the cheapest possible buildings which, in the shape of schools, hospitals, department stores, theatres, hydroelectric power stations, bridges and other structures, are an indispensable part of modern life. It will be a long time before human beings will be able to resist the mass use of concrete or reinforced concrete. Our aims are always greater and higher. Some attempt is made to ease the increasing use of reinforced concrete by means of more distinctive design of reinforced concrete structures. This perhaps works best in the case of bridges, which are very much in the public eye and which have the greatest effect on the environment in which they are built.

Concrete will undoubtedly be with us for a long time to come. For this reason a knowledge of the history of the use of this material will the construction engineers and architects of today and tomorrow understand the influence of reinforced concrete constructions on the quality of human life.

The first concrete and reinforced concrete bridges, heralds of a new era in bridge-building, were already beginning to appear at the end of the 19th century. This period also saw the construction of the largest stone bridges, which still outdid concrete bridges in terms of size. But stone bridges were very soon forced to give way to concrete, which was becoming increasingly established as a building material. Planners competed among themselves as to who could build the largest bridge, be it of steel, stone, brick or concrete. While steel bridges had already easily passed the 100-metre-span mark, stone bridges struggled to approach such lengths, never in fact achieving it. The ‘last gasp’ of the several-thousand-year era of stone bridges was the building of the great railway bridge over the River Soča at Solkan (Slovenia), whose 85-metre span made it the largest cut stone arch in the world (1906), and the almost simultaneous building of the bridge across the Syra Valley at Plauen (Germany), whose quarry stone arch had a span of 90 metres.



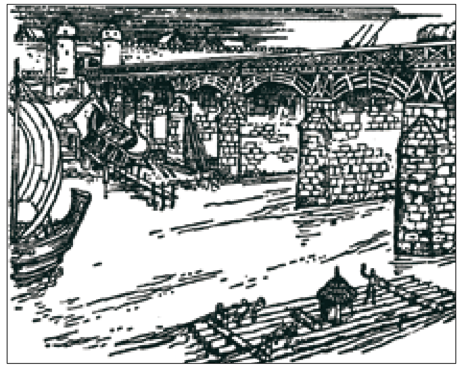
The bridge over the Soča at Solkan (Slovenia) has the largest stone arch of any railway bridge in the world. The span of the main arch, which is built of cut stone, measures 85 metres. It was built in 1906 and at that time represented the pinnacle of engineering skill as applied to the construction of stone bridges. At the same time it was also the last large bridge of the stone bridge era – a period that had lasted thousands of years. Immediately after its construction, the era of large concrete bridges began.

Photo: Bogdan Kladnik

The bridge over the Tiber in Rome was the first reinforced-concrete bridge in the world to reach a span of 100 metres. It was built between 1910 and 1911 by the French engineer François Hennebique.

After 1905 the construction of large stone bridges died out almost entirely, since concrete, already a well-established and tested material, had practically superseded stone as the principal building material. By as early as 1911, Hennebique had built a bridge with a 100-metre span over the Tiber in Rome, thus opening the way for future generations of large reinforced concrete bridges.

But even concrete, as a completely new building material, experienced a series of difficult tests at the beginning of its career, and the constructors of the first concrete bridges suffered numerous disappointments. Let us look at how concrete, as a newcomer in the world of building materials, began its difficult journey.

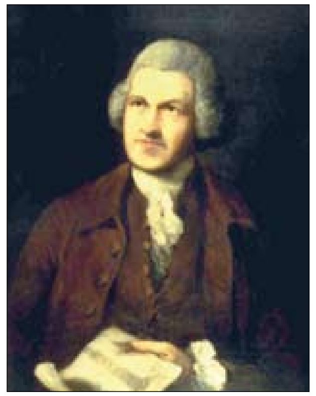


Trajan's Bridge over the Danube, built between AD 103 and AD 104.

How concrete came to prominence

Concrete is not in fact a 19th century invention. The Roman writer Vitruvius tells how even the Ancient Romans produced a type of concrete - concretum - which was successfully used in the construction of bridges and aqueducts. This concrete was also used in the construction of the 22 piers of the famous Trajan Bridge over the Danube at Kladovo (the main load-bearing bridge construction was made of wood and had a span of 52 metres).

Knowledge of the use of concrete died out with the fall of the Roman Empire and concrete had to wait long centuries before it was rediscovered. The essence of concrete was cement that, when water was added to a concrete mixture gave it, after a while, the necessary hardness. Another very important property is that it can also harden under water. This of course was not a property of the lime mortars which man had used for centuries as a binding agent in practically all building constructions.



John Smeaton (1724–1792) discovered the first hydraulic cement.

The discovery of the first hydraulic cement, capable of hardening under water, came about in England in 1756 when John Smeaton (1724-1792) added to a lime mortar a material made from river alluvia. These however were simply first experiments. An important year for the cement industry was 1816, the year that saw the first beginnings of the modern hydraulic cement industry. The first person to heat a mixture of lime and clay together at high temperature was the Frenchman Louis Vicat (1786-1868). Through this process he invented the first artificially manufactured hydraulic cement. He used the new cement in the construction of a bridge across the River Dordogne at Soullac in France.

Another important discovery in the field of cement followed shortly. In 1844 the Englishman Isaac Charles Johnson (1811-1911) chanced upon the first Portland cement, as it is still known today. Johnson was the manager of a lime cement factory and one day, during an experiment, he overheated the mass he was heating in the kiln, with the result that it began to melt. He then ground up this compound finely and, considering it unsuitable, threw it into a damp corner where it remained for several weeks. He noticed that the ground compound mixed with water quickly hardened and no longer disintegrated in water. He now devoted great attention to the clinker compound, studying it further and improving it by means of a 2% addition of gypsum. This additive enabled him to regulate the binding time.

Luis Vicat (1786–1868) invented the first artificially manufactured hydraulic cement.

Johnson exploited his invention diligently. Orders for the new cement rained in. Soon, other Portland cement factories began appearing in England, for the manufacturing process could not stay secret for long. Slowly continental Europe began to wake up to the new invention and readied itself for the manufacture of a material that had begun to change significantly its outward appearance. An extremely telling piece of data is the fact the production of Portland cement in Europe in 1850 amounted to around 68,000 tons, while in 1880 it had already reached 1,700,000 tons.

Bottle kiln for the production of cement, built in 1853 by Joseph Vicat (1821–1902) at Genevrey-de-Vif, France.

The invention of hydraulic cement in the 19th century coincided with the growing industrialisation of Europe and the ever faster development of the railway network. Thus the introduction of concrete into construction was more than timely. However concrete did not establish itself as quickly as might have been expected. Despite the usefulness of concrete builders still had many reservations about the material. Concrete had still not been tested enough, and not enough was known about its mechanical properties. Unsuitable preparation of the mixture, with a lack of proper tools and apparatus, was to represent a serious obstacle for a long time to come. The life expectancy of concrete was also open to question, since no-one had yet been able to gain the necessary experience of its durability. All of this meant that concrete was only able to make slow and modest progress in bridge-building. Although steel constructions at that time were already achieving enviable spans, bridge-builders, and especially investors, did not entirely trust steel either. The increasingly extensive construction of steel structures was held back by the consideration of the high costs of maintenance of steel bridges because of the need to protect them against rust.

The case of the bridge over the River Yonne is instructive

Very interesting and instructive from the point of view of the history of the use of concrete in bridge-building is the case of the bridge over the River Yonne (a tributary of the Seine) near Paris. This bridge, built in 1870-1873, can rightly be considered one of the first large concrete bridges in the world. The experiences, or rather the misfortunes, involved in the construction of this 1460-metre-long bridge had almost fatal consequences on the future development of concrete bridges, so much so that the use of concrete in bridge-building was set back quite some years. Another result was that confidence in concrete as a good and reliable building material declined sharply.

The bridge over the Yonne was in fact an aqueduct supplying Paris with water via two buried pipes 110 centimetres in

The bridge over the river Yonne in France (built 1870–1873) has the largest non-reinforced concrete arch in the world, with a span of 40 metres. The construction of this bridge was very instructive and had a decisive influence on the further destiny of the first concrete bridges.

diameter. Running from the left bank to the right was a series of arches with spans of 12 metres, 22.6 metres, 30 metres, 40 metres, 30 metres and 12 metres respectively. The remaining 149 arches had spans ranging from 6 to 12 metres. The largest, elliptical arch, with a span of 40 metres, was 110 centimetres thick at its crown.

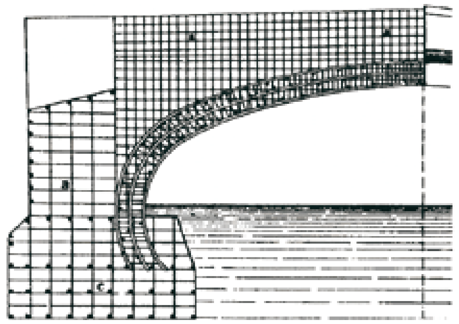
The concrete arches of the Yonne bridge were built from hand-fixed concrete applied horizontally. The first difficulties actually appeared when it came to removing the wooden supporting platform from under the largest arch (8 and 9 November 1870). Wide cracks appeared in the arch itself, while in places the concrete began to crumble. Because of this the builders were forced to break up the largest 40-metre arch and the neighbouring 30-metre arch and re-concrete them. Once again they concreted them in horizontal layers, this time leaving 13 breaks or empty interspaces between the individual longitudinal sections of the concrete arch (previously there had been only two). The second time the supports were removed, two months after the two arches had been re-concreted, cracks again appeared near the crown and on a quarter of the span of the largest arch. Moreover there was a horizontal shift of the abutment. The concrete arch was once again supported by a wooden platform and the damaged part repaired.

On 3 August 1872 the builders once again began removing the supporting platforms from the three largest arches. A crack appeared in the crown of the largest arch for the third time, as though it were cursed. The damaged section was again removed and built up again (not concreted!) with stone blocks in a cement mortar.

The fourth attempt to remove the platform, on 1 April 1873, was successful. No cracks appeared. One can imagine the disappointment of the aqueduct's builders, and the reaction to this project among other members of the profession. Confidence in concrete as a suitable material for bridge-building was strongly shaken by this unfortunate episode, and in fact the experience served to further increase interest in the construction of stone bridges, which had reached its culmination at the turn of the century and then a few years later gone into almost total decline. But the problems suffered by concrete in the first few decades of its life were merely teething troubles and nothing could stop it predicting a dominant role in the construction of bridges, harbours, dams, pillars and many other structures.

The introduction of reinforced concrete

A look at the history of building shows us that for thousands of years the arch or vault was dominant as the main load-bearing construction in all types of structure. This important and later constructively well developed construction dominated in all large structures built by man, whether bridges, amphitheatres, coliseums or (later) cathedrals and castles.

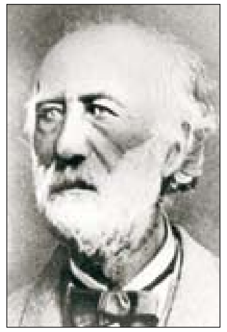


The first reinforcement plan in the world, enclosed with his patent application by the French gardener Joseph Monier.

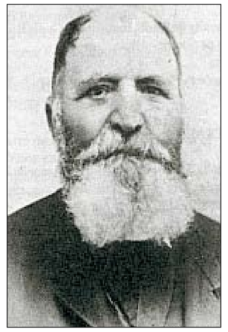
The chief materials to be used in arch constructions were stone and brick. With both of these materials man skilfully exploited their most important mechanical property - a high tensile strength. Both stone and brick are very good at supporting tensile stresses, the only stresses that usually occur in arch constructions. This was the reason that the arch was the most used and most widespread load-bearing construction. The arch answered man's requirements perfectly right up until the middle of the 19th century, when man discovered a way of building even when shear stresses occur - something which stone and brick are unable to withstand. The need to cope not only with tensile stresses but also with shear stresses was best answered by reinforced concrete, i.e. concrete into which iron rods are built.

Today reinforced concrete is predominant in the majority of construction projects, since from both the economic and technical points of view it is difficult for other materials to compete.

Lambot and Monier were the first to use reinforced concrete



Joseph-Louis Lambot

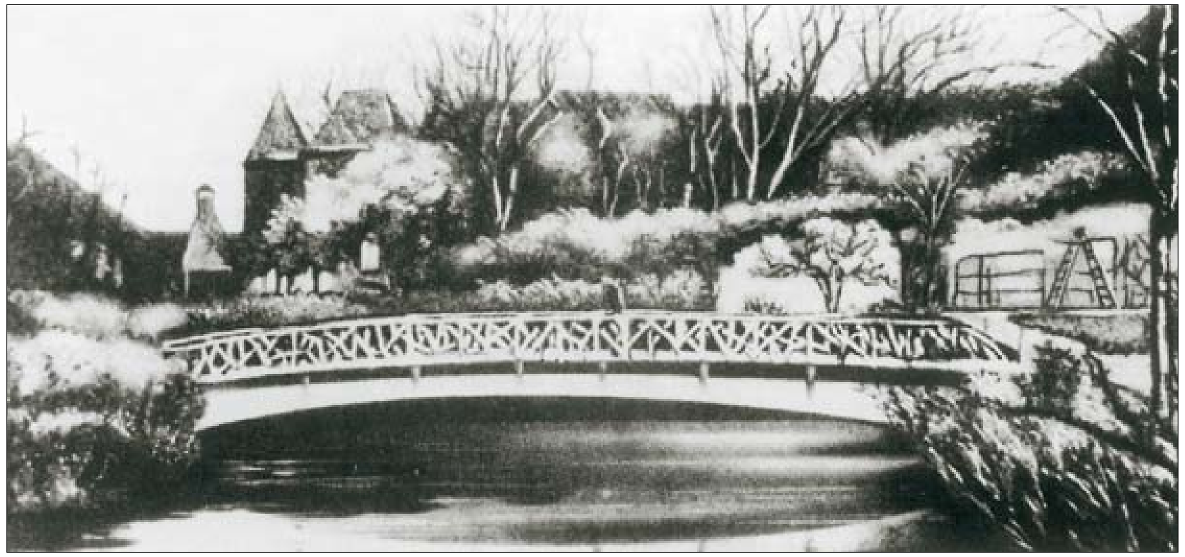


Joseph Monier

By the mid-19th century the improved properties of cements led to the use of better and better quality concrete. Many engineers soon began to realise the advantages of concrete as a brand new construction material. The first man to look seriously at the use of a combination of iron rods and concrete was the French engineer Joseph-Louis Lambot (1814–1887). In 1841 Lambot constructed the first ferro-cement water tanks on his family estate in the south of France. In terms of their construction, these were the predecessors of what is today known as reinforced concrete. In 1848 he built a ferro-cement boat, which he patented in 1855.

Even more skilful and inventive than Lambot, however, was his countryman Joseph Monier (1823–1906), a gardener. What happened was that Monier used to make his own flower pots, but most of them broke, and were thus useless. He tried to solve this problem by adding a wire to the mixture out of which he made his pots.Thanks to the addition of the wire cracks no longer appeared in the flower pots. Monier, who was extremely enterprising, used his idea successfully and soon achieved enviable results. The inventive gardener did not entirely understand the essence of reinforcement (the withstanding of shear stresses in concrete), rather he understood the role of iron in concrete as something that gives concrete the necessary basis for achieving specific forms and shapes. He therefore patented this method in 1867.

On 13 August 1873 Monier had already acquired a second patent. To gain it he had taken a step forward in his understanding of the essence of reinforced concrete. He enclosed with the patent documentation a sketch showing the course of cylindrical iron rods in the concrete arch construction of a



The bridge in the park of the Marquis de Châzelet at Châzelet, France was the first reinforced concrete bridge in the world. It was built using the Monier system in 1875 and still stands today, though in a somewhat dilapidated state.

bridge. This sketch can be considered the first reinforcement plan ever drawn up.

The Monier system, as the first method of reinforcing concrete was then known, soon spread across France. In 1875 the first reinforced concrete bridge was built, in the park of the Marquis Tilière de Chazelet at Chazelet, near Bourges, in France. The bridge had an arch construction of a fairly shallow shape, a span of 16.5 metres and a breadth of 4 metres. A special feature of this bridge was that its parapet, also made out of reinforced concrete, gives the impression from a distance of being made out of branches. The bridge, which is situated in a private park, still stands today, though in a slightly damaged state.

Monier did not know how to use the profits his patents brought him. He died in 1906, almost forgotten and in financial hardship.

The use of the Monier system spreads rapidly throughout Europe

After 1880 the Monier system won more recognition in Germany and Austria-Hungary than in France. The pioneer of reinforced concrete in Germany was Gustav Adolf Wayss (1850 - 1917). In 1884 Monier's patent was bought up by the firms of Freytag & Heidschuh and Martenstein & Jorseux. A year later this patent was taken over by G. A. Wayss, a partner in the large German construction company Wayss and Freytag, which even today is still a very well known firm. In Berlin, Wayss founded a construction company specialising in the Monier system. His chief merit is that he began a scientific study of the behaviour of reinforced concrete. He did this in order to banish the doubts that existed in Germany about its serviceability, and to demonstrate the useful properties of reinforced concrete.

In 1886 Wayss published a report on the testing of concrete and reinforced concrete arches, which was based on numerous researches and experiments which he had himself conducted. The tests showed that reinforced arches built according to the Monier system support a load almost three times greater than that supported by non-reinforced concrete, even in the case of asymmetric loads.

In 1887 Wayss published the 'Monierbroschüre', the first written work on the Monier system, under the title 'The Monier System and its Application in Construction'.[1]

In Austria the Monier system was first propagated by the Austrian Rudolf Schuster (1880). From Monier he purchased the right to extend the Monier patent across the entire Austro-Hungarian Empire. However the enterprising G. A. Wayss soon bought Schuster's right to use the patent in Austria-Hungary and to this end founded in Vienna the firm of Wayss & Co., Wien.

In collaboration with the German engineer Matthias Koenen (1849 - 1924), Wayss built several of small reinforced concrete bridges. The most successful result of their co-operation was a reinforced concrete footbridge with a span of 40 metres. This bridge, built in 1890 at the exhibition grounds in Bremen, Germany, was 4.5 metres high, while the thickness of the arch at the crown was a mere 25 centimetres. The bridge was a remarkable achievement for its time in the use of reinforced concrete, and above all this construction confirmed the value of all the research into reinforced concrete that had been conducted to date. Among the most important results of the research into reinforced concrete was the report by Bauschinger of Munich published on 20 December 1887. The report found that:

- between the concrete and the iron a strong connection is created
- even if exposed to great and rapid temperature changes the iron does not separate from the concrete
- the iron rods surrounded by the concrete are not affected by corrosion even after long periods.

Reinforced concrete arch bridge with a 40-metre span built in 1890 at the exhibition grounds in Bremen, Germany. At its thinnest point the arch measured just 25 cm.

These principal findings, very important even today, threw the doors open to the use of reinforced concrete. Particularly important was the finding that under the influence of temperature changes the concrete and iron expand or contract at the same rate. This favourable property, which does not cause separation of the iron and the concrete and which allows both materials to work in harmony during temperature changes, is especially important for bridges, which of all structures are perhaps most exposed to intense daily temperature changes.

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[1] Das System Monier im seiner Anwendung auf das gesamte Bauwesen, 1887.

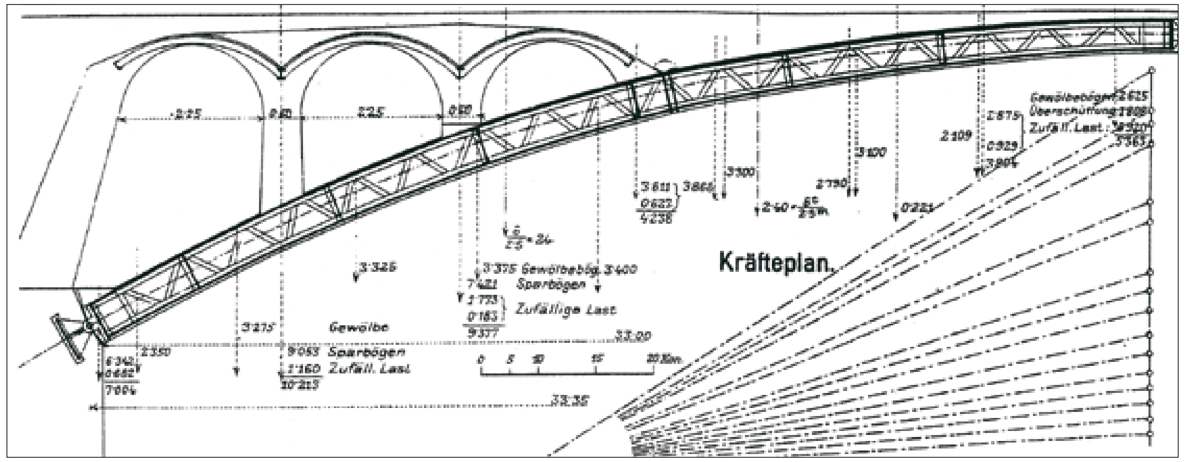
Load test of a concrete arch bridge carried out by Austrian engineers at the end of the 19th century.

Extensive research into concrete is carried out in Austria

Austrian engineering enjoyed a boom in the 1880s, particularly in the area of bridge-building. Familiarity with the use of concrete and the behaviour of solid arch bridge constructions was of great importance for Austrian engineers, since the Austro-Hungarian Empire was engaged in the construction of numerous railway lines, on which countless bridges had to be built - although even at the beginning of the 20th century the bridges being built for the Austrian railway were still almost exclusively of stone. Nevertheless intensive studies of the behaviour of concrete in bridge structures were carried out. Important in this respect were the load tests carried out in Vienna in 1889 on a 10-metre model arch bridge on behalf of the Southern Railway company (a similar experiment was carried out by Bauschinger in Munich in 1887). Also interesting are the series of experiments carried out in 1890-92 by the engineer V. Purkersdorfer on a several identical arches made of different materials. On the basis of his measurements Purkersdorfer was able to prove that reinforced concrete (Monier system) had a significantly higher load-bearing capacity even in the case of an arch of small thickness than arches made of unreinforced concrete, stone or brick. A joint report on tests of arch constructions was published by the Austrian Association of Engineers and Architects (ÖIAV) in 1895. The report contained the primary conclusions of the tests, particularly important among which was the account of the elastic behaviour of solid arch constructions. The so-called theory of elasticity of structures is still today the foundation of construction science.

The introduction of hinges into bridge-building

With the growth in the size of spans, both with stone and iron bridges and, soon after, with concrete bridges, the great sensitivity of solid bridge constructions to movements of parts of the structure, whether caused by movement of the foundations of the abutments or intervening piers, or by the influence of temperature changes on the structure as a whole, came more and more into the foreground. Movement occurs in bridges for various reasons - unstable ground, poorly made foundations, undermining of the bridge structure through erosion, etc. The introduction of hinges made the bridge structure more flexible, soft, and less sensitive to movements and expansion or contraction caused by temperature changes. If small movements occurred in a hinged bridge structure, the structure could absorb them relatively simply and without consequences through the twisting of its jointed elements. The introduction of hinges also made the static calculation of a bridge structure simpler, so bridge-builders were happy to resort to this solution, especially in earthquake areas and in cases of unstable ground.



Part of the plan of the iron truss girders built into the Dragon Bridge in Ljubljana (1901), Slovenia. The bridge was built according to the Melan system.

The first person to built hinges into stone bridges was the French engineer Dupuit. In 1870 he published an article[2] in which he laid down the theoretical basis for the introduction of hinges into solid bridges. Interestingly Dupuit's idea met with little response in France, and was most enthusiastically received by the Germans. The great majority of stone and concrete bridges in Germany were built as hinged arch constructions. The hinging of bridges in Germany was first introduced by Köpcke in Dresden in 1880. All the hinged stone arch bridges built in Europe had triple-hinged arches.

More than in masonry bridges, however, hinges really began to come into their own in iron bridges. In 1867 a cast-iron bridge was built over the river Ljubljanica in Ljubljana (Slovenia) to the plans of chief engineer Johann Herman of Vienna. The supporting structure of this bridge represented, in the static sense, a triple-hinged arch with a span of 30 metres. The bridge is still standing today and represents one of the finest technical monuments in Europe from the second half of the 19th century. This bridge is believed to be the oldest hinged cast-iron bridge in Europe still in use today.

The famous bridge-builder Gustav Eiffel also made frequent use of hinges in the construction of his iron bridges. One of the finest such examples is the Garabit Viaduct in France, built in 1884. Its double-hinged arch with a span of 165 metres made it the largest arch bridge in the world at the time.

Dragon Bridge – part of the main arch with 3 hinges.

The Shoemakers' Bridge in Ljubljana was one of the first cast-iron bridges in the world to incorporate hinges. It was built in the year 1867 by the Austrian engineer Johann Herman.

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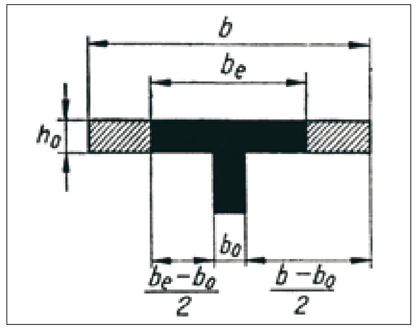
[2] "Traité de l' équilibre des voûtes et de la construction des ponts en maçonerie", J. Dupuit, Inspecteur général des Ponts et Chaussées, Paris, Dunod, 1870.

France once again takes the initiative in the construction of reinforced concrete bridges

François Hennebique (1842–1921)



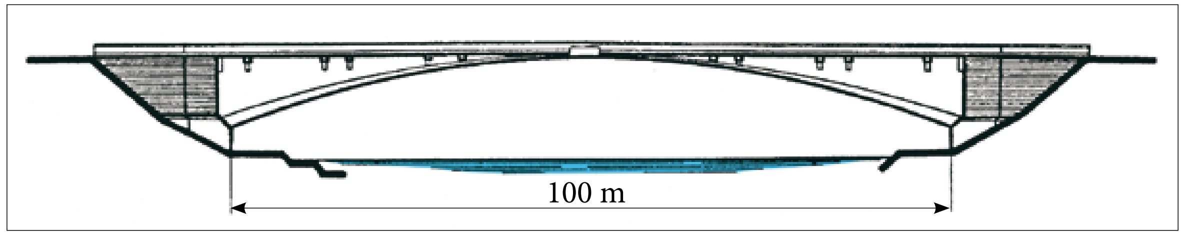
T-beam. François Hennebique was the first engineer to divide a reinforced-concrete structure into intermediate ribs with a flat deck resting above them. In this way he was able to take full advantage of the supporting cross-section and significantly reduce the weight of reinforced concrete structures.

An outstanding figure in the period of the initial development of reinforced concrete constructions was the Frenchman François Hennebique (1842-1921). A stonemason by profession, he quickly became a building contractor, and combined in himself two important characteristics. Above all he was an excellent engineer, with an exceptional feeling for the design of constructions with regard to the internal forces operating on them; furthermore he was also a successful businessman who successfully marketed his knowledge by means of licences. Hennebique was the first to fully understand the role of both iron and concrete in reinforced concrete. The result of his reflections, in which he saw the role of the iron as the withstanding of shear stress and the role of the concrete the withstanding of tensile stress, was the production of the first T-shaped support. With the introduction of the T-support Hennebique became the first person to break down a reinforced concrete construction into supports, main and secondary, and a slab lying above.

He developed this type of construction, still very widespread today, in 1892, and immediately patented it. The essence of the T-support in conjunction with the monolithic slab lying above it also lay in the rational exploitation of the material, which led directly to a reduction in the weight of structures and thus to a lowering of construction costs. Hennebique patented the result of his research and successfully sold licences to an increasing number of construction companies all over Europe. In 1902 Hennebique was supervising the work of roughly 500 licensee firms from his central office in Paris. By 1906 this number had risen to 700 companies, from which he received a licence fee amounting to 10 per cent of the construction costs of every structure under construction. By 1910 Hennebique had already issued licences to 1500 companies.

Quite apart from his enterprise, Hennebique must be given much credit for his work in the field of the development of structures, especially in the field of the construction of large arch bridges. One of the first structurally disjointed arch bridges was built in 1899-1900 in the town of Schwehat (now a suburb of Vienna) in Austria. This bridge, which boasted disjointed girder supports, had an arch span of 23.6 metres. Another, considerably larger Hennebique bridge was built in Châtellerault, in France, at the same time. This bridge had three arches with spans measuring 40, 50 and 40 metres respectively, and is one of the most clearly statically and structurally disjointed bridge constructions of the time. In constructing this bridge Hennebique demonstrated in the best way his great talent as an innovator and outstanding natural abilities as a constructor.

The Ponte del Risorgimento in Rome, built by Hennebique between 1910 and 1911, was the first reinforced-concrete bridge in the world to boast a span of 100 metres.



The Hennebique office in Paris was entirely built of reinforced concrete (1901).

Hennebique was capable of one more surprise. Between 1910 and 1911 he built in Rome an arch bridge with an exceptionally low arch which was the first reinforced concrete bridge to achieve a span of 100 metres. The Ponte del Risorgimento over the River Tiber in Rome was built by Hennebique (who had won the contract in an international competition) in just fifteen months, despite the exceptionally difficult conditions caused by the poor base for the foundations. This success placed his name permanently among the greats in the area of construction and the development of bridge-building.

Construction of reinforced concrete bridges by the Melan system

The problem of reinforcing bridge structures was solved in his own original and interesting way by the Austrian engineer Dr Joseph Melan (1853-1941), known in Slovenia as the builder of the Dragon Bridge in Ljubljana. The same year that Hennebique patented his T-support (1892), Melan registered his patent for the construction of reinforced bridges. Melan's method, known as the Melan system, differed from the Monier system in that he did not build cylindrical iron rods into the reinforced concrete bridge structure but instead used rigid iron trusses made of riveted angle iron.

Melan completed his studies at the Technical College in Vienna and in 1880 qualified as a private lecturer. From 1893 onwards he was employed as professor of bridge studies at the Technical College in Brno, while from 1902 onwards he taught in Prague. Unlike Hennebique, who was a successful businessman, Melan only ever planned bridges in his capacity as a university professor. He also deserves credit for the publication of a four-volume textbook entitled Der Brückenbau which contains a scientific treatment of the problems relating to the construction of wooden, stone, iron and reinforced concrete structures. For decades these textbooks were the standard scientific works on bridge-building.

Less well known to the general public is Melan's study of the behaviour of arch bridges and suspension bridges under the influences of variable stress,[3] which he presented in 1888. In it he gives, in addition to a method of static treat-

The supporting core of bridges built using the Melan system are iron truss girders.

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[3] Entwicklung und Darlegung der genauen Theorie der Bogen und Hängebrücken bei Berücksichtigung der Verformungen unter der jeweiligen Lasteinwirkungen

Dr Joseph Melan was the father of the theory of structural behaviour of large suspension bridges. His theoretical research provided a basis for planning and building the largest bridges of this type, including the Golden Gate Bridge in San Francisco. This bridge, built in 1937, held the world record for the longest main span (1280 metres) until 1964. The supporting cables are 90 centimetres in diameter. The Golden Gate is probably the most famous bridge in the world.

ment of arch supports, the theoretical basis of exceptional importance for the calculation of suspension bridges. Melan's theory of the calculation of suspension bridges gave the basis for the calculation of the most famous and important suspension bridges, pre-eminent among them the George Washington Bridge in New York (built 1931) and the Golden Gate Bridge in San Francisco (built 1937). Both bridges broke the world record for the length of span of the main load-bearing field, the Golden Gate Bridge holding the record right up until 1964 when it was overtaken by 18 metres by the Verrazano Bridge in New York.

The birth of prestressed concrete – and its father is Eugène Freyssinet

The early 20th century brought rapid development of reinforced concrete structures, which began to supersede stone and brick in all spheres of civil engineering, but particularly in bridge-building. Inexpensiveness, solidity and speed of construction are the essential elements that enabled spread of concrete structures into all spheres. More and more engineers and scientists began researching the properties and areas of application of concrete, which became the main construction material of the 20th century. Research was (and still is) under way in every country in Europe to try and remove the last veil of mystery from concrete.

Edme Campenon (left) and Eugène Freyssinet with their colleagues.

Early in his professional career, the young French engineer Eugène Freyssinet (1879–1962) was constantly looking at how best to exploit the properties of reinforced concrete, reduce the weight of structures and optimise the dimensions of reinforced concrete construction elements. Having realised his first extremely simple prestressed structure between 1907 and 1908, Freyssinet was to remain obsessed with the idea of prestressing for the remainder of his long career. After the end of the First World War and a period in which he worked above all with Claude Limousin, he submitted a patent application together with his friend Jean Séailles on 2 October 1928. It was not until 22 January 1930 that a patent was issued for their method for the production of reinforced concrete elements.

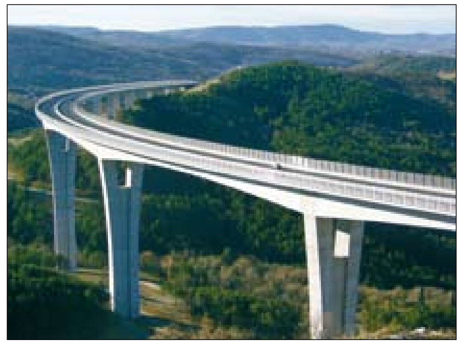
The word 'prestressing' was used in this sense for the first time in a patent application published in Germany in 1929. We may therefore assume that Freyssinet borrowed this expression from the Germans, using it for the first time in a technical report in 1933.

Freyssinet enjoyed his greatest professional triumph with the successful engineering intervention (using the prestressing method) which he employed to save the passenger terminal (Gare Transatlantique) in Le Havre, which had begun to sink into the mud of the sea bottom. His successful rescue of the 600-metre-long passenger terminal won Freyssinet great fame, not just in France but around the world.

It was in Le Havre that Freyssinet first met Edme Campenon, the president of the great Campenon-Bernard construction company. Together they realised a number of major projects in Algeria, among them a bridge with prestressed supports. This was the service bridge for the Oued Fodda Dam, built between 1937 and 1939. This is the first known example in the history of civil engineering of the practical and successful use of prefabricated and prestressed concrete supports (I-girders). The dam and the service bridge (both built from prefabricated prestressed concrete elements) are still in use today.

Use of Freyssinet's 1929 patent spread rapidly throughout Europe, particularly in Germany. In 1934 Karl Mautner entered a licence agreement with Freyssinet on behalf of the engineering firm Wayss & Freytag. Besides Mautner, other German engineers who successfully used the prestressing system included Emil Mörsch, Franz Dischinger and Ewald Hoyer.

The development of prestressed structures was to advance very rapidly from this moment on. With the use of better steel and more solid concrete, the use of prestressed structures expanded into every sphere of the construction industry in the second half of the 20th century, and in particular into bridge-building, where we continue to see new applications of this method – perhaps the most significant advance in civil engineering of the 20th and 21st centuries.



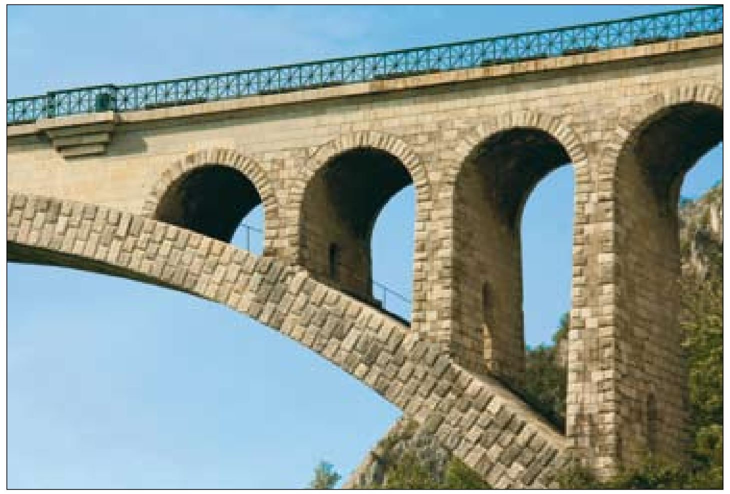
The Črni Kal Viaduct in Slovenia built using the free cantilever method and the Freyssinet post-tensioning system (C-Range).

Cable-stayed bridge over the Morača in Podgorica (Montenegro). For the construction of the bridge, which has a main span of 145 metres, Freyssinet post-tensioning and cable stays were used (2004).

The Eiffel Tower in Paris, as captured in the lens of the internationally acclaimed photographer, aesthete and philosopher Evgen Bavčar, who divides his time between Slovenia and Paris.
His extraordinarily creative personality is also shaped by the remarkable fact that he has been totaly blind since the age of 12.

Gorazd Humar, editor-in-chief

Contributions of ECCE members



Man built too many walls
and not enough bridges

Isaac Newton (1642 – 1727)

Croatia

BUILDINGS

- **Đakovo Cathedral**
- Đakovo
- 1882
- Built in Romanesque-Gothic style

The cathedral was built in the period 1866-1882, during the service of Bishop Josip Juraj Strossmayer, by Vienna builders Karlo Rösner and Friedrich Schmidt, achieving a monumental structure in the Romanesque-Gothic style. Its geometric characteristics are: towers 84 m high, dome 59 m - interior 40 m, length of the cathedral 74 m, height of the central nave 27 m, length of transverse nave 52 m.

The interior features 43 large frescoes with biblical motifs from the Old and New Testaments. The frescoes are the work of German painters Alexander Maximilian Seitz and Ljudevit Seitz, and the Italian painter Ljudevit Ansiglioni.

The cathedral has seven altars. The area under the main dome where the transverse and longitudinal centerlines intersect is dominated by the main altar, dedicated to St. Peter, the cathedral's patron. The Cathedral also has 31 stone sculptures, the works of sculptors Vatroslav Donegani, Tome Vodički and Georg Feuerstein. The piers, vaults and wall surfaces are richly ornamented with works of the painter-decorator Josip Voltolini. In the cathedral basement is an ornate crypt with stone relief, with graves of previous bishops.

The cathedral organs, the work of the Steinmayer Company from Ötingen in Bavaria, were destroyed by fire in 1933. The present organs are the work of Franc Jenko from Šentvid, Slovenia.

Croatia

BUILDINGS

- **Zagreb Cathedral**
- Zagreb
- 1880 - 1902
- Two 105 m-high towers

The cathedral's present external features date from the 19th century. It is the largest church in Croatia, with towers 105 m high and five belfries. The cathedral can accommodate over 5000 visitors. It was built on the foundations of a Pre-Romanesque or Romanesque church. The cathedral was part of a medieval castle, and when the west wall was brought down, Kaptol Square was formed in front of the cathedral.

Croatia

BUILDINGS

- **National Theatre**
- Zagreb
- 1895
- Built in neo-Baroque style

A new theatre building was formally opened in Zagreb in 1895, which could host 750 visitors, and the Croatian National Theatre still performs in it today. It is a neo-Baroque-style building, a masterpiece of Late Historicism. The building was reconstructed during the 1960s, but kept its main features and appearance.

The designs for the building were commissioned from the renowned Vienna architects Ferdinand Fellner and Herman Helmer, the authors of some forty theatres throughout Europe. After only sixteen and a half months of work, the building was completed, exactly according to plan, and was opened on 14 October 1895.

The Croatian National Theatre building in Zagreb is situated among numerous other buildings of cultural and historical significance which represent Croatian architecture of the late 19th and early 20th centuries. With only one reconstruction project in the late 1960s, the building kept its main design parameters and the intended use of the interior. This same building has served as the home of Croatian stagecraft for more than 100 years, where drama, opera and ballet have coexisted continuously and successfully.

Croatia

BUILDINGS

- **Art Pavilion**
- Zagreb
- 1898
- Constructed in 1896 for the Millennium Exhibition in Budapest, in 1897 relocated to Zagreb

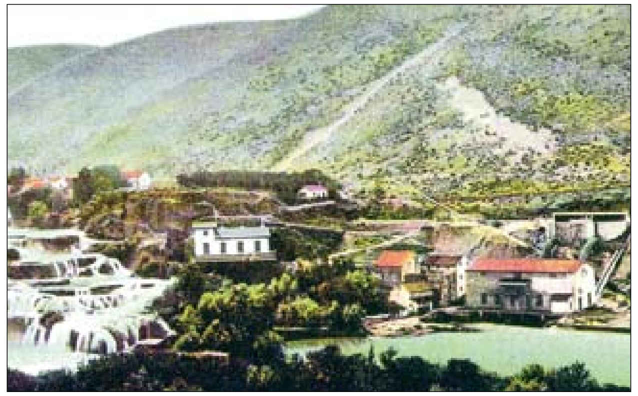
The history of the Art Pavilion in Zagreb in a sense narrates the history of Croatian art of the past century. It is the oldest exhibition area in the Slavic west and the only structure purposely built to host large-scale and representative art exhibitions. During its 100-year existence, the Pavilion hosted almost all important exhibitions that went beyond the local boundaries. Our culture never was a closed or exclusive one, but always oriented towards the whole world. The Art Pavilion was a place where renowned artists from other cultures and areas were always welcomed.

The idea and initiative to build such an Art Pavilion was given by the painter Vlaho Bukovac in 1895. This idea became a reality with preparations for the Millennium Exhibition in Budapest, which was to be officially opened on 2 May 1896. On the initiative of Bukovac, Croatian artists asked that a separate, prefabricated art pavilion be constructed in Budapest for their needs, whose steel frame would then be transported to Zagreb after the exhibition closed. This idea went as planned and an invitation was published for construction works on the Art Pavilion. The task was given to the Vienna architects Hellmer and Fellner (well know designers of theatres). The actual construction was done by the Zagreb builders Honigsberg and Deutch, under the supervision of the town engineer M. Lenucij. The works were completed during 1897 and 1898, and the Pavilion was officially opened on 15 December 1898 with a representative exhibition “Hrvatski salon”.

Croatia

Hydroelectric Power Plants in Croatia at the end of the 19th and the beginning of the 20th century

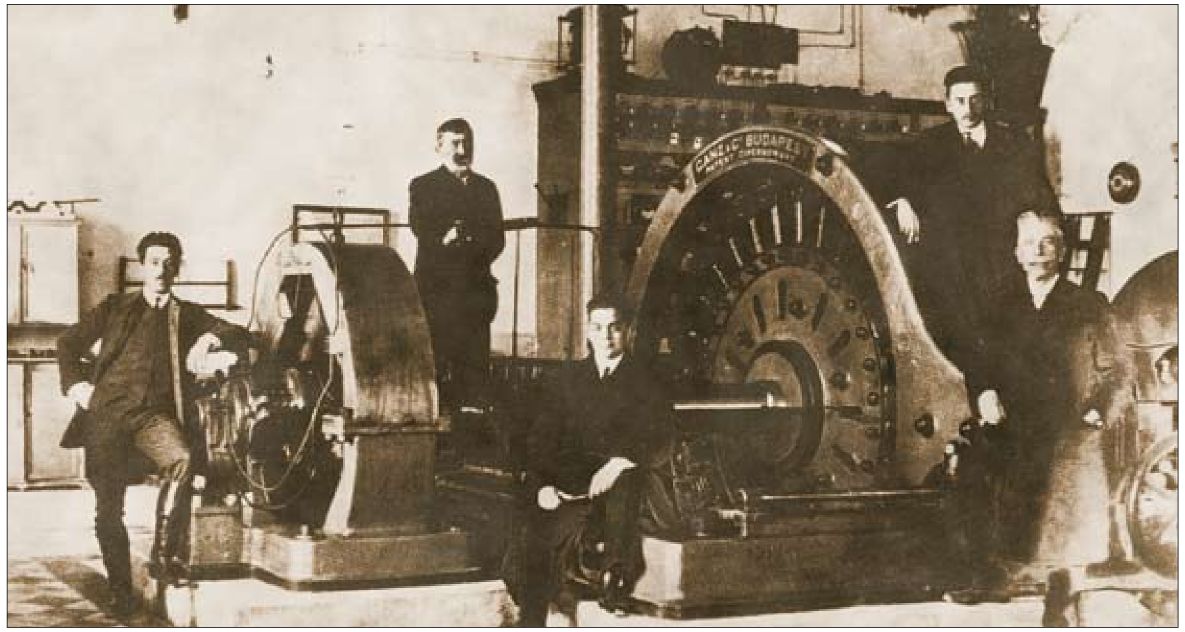
Croatia's tradition in building HPPs is more than 100 years old. The first Hydroelectric Power Plant (HPP), Jaruga 1, was built in 1895, only 3 years after HPP Niagara (USA), which was the first commercial plant in the world. During the next ten years, four more HPPs were built: HPP Jaruga 2 (1903), HPP Miljacka (1906), HPP Ozalj 1 (1908) and HPP Kraljevac (1912). These four HPPs are exceptional examples of industrial architecture at the end of the 19th and beginning of the 20th century. To this day, all four are still in operation.



HYDROPOWER PLANTS

- **Jaruga 1 and Jaruga 2 HPP**
- Krka River, near the city of Šibenik
- 1895 Jaruga 1 HPP
- 1903 Jaruga 2 HPP
- The Jaruga 1 HPP is one of the oldest HPPs in the world

The Jaruga 2 Hydroelectric Power Plant (HPP) is also one of the oldest power generating facilities in the world. Its present location dates back to 1903, and it is located in the vicinity of the even older Jaruga 1 HPP from 1895. The Jaruga HPP is located on the Krka River some 10 km from the city of Šibenik and the Adriatic coast. It uses a gross head of about 26 m. Installed capacity is 5.4 MW and average annual output 35 GWh.



Croatia

HYDROPOWER PLANTS

- **High-pressure Miljacka HPP**
- Krka River
- 1906
- All structures are made of stone with lime mortar as a binder

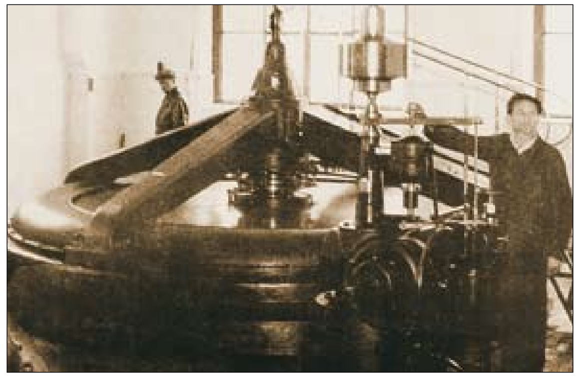
The high-pressure Miljacka HPP was built in 1906 on the Krka River. The power plant's capacity is 24 MW and average annual output 116 GWh. The Miljacka HPP uses a gross head of 106 m. The water was impounded by construction of the dam which forms the Brljan Reservoir. There are also a 1620 m-long headrace tunnel, two open surge chambers and four 108 m-long penstocks, as well as a powerhouse with four horizontal-shaft generating units. All the structures date from 1906, and they are made of stone with lime mortar as binder. Cement was used only for grouting of the generating unit anchors. These structures have been preserved in their original form.

Croatia

HYDROPOWER PLANTS

- **Ozalj 1 HPP**
- Near the city of Karlovac
- 1908
- An exceptional example of industrial architecture

The Ozalj 1 HPP is one of the oldest hydroelectric power plants in Croatia. It was built in 1908 and intended for street lighting for the city of Karlovac. During the first stage, two generating units were installed, while a third was added in 1913, so its total capacity at that time was 3.3 MW. The Ozalj 2 HPP was built in 1952, and it is fitted with two generating units with a total capacity of 2.2 MW. The Ozalj 1 HPP powerhouse was built as a Neoclassical building and is an exceptional example of industrial architecture from the early twentieth century.



Croatia

HYDROPOWER PLANTS

- **Kraljevac HPP**
- On the Cetina River
- 1912
- The structures have been preserved in their original form

The Kraljevac HPP (first stage) was built in 1912 and is located on the Cetina River some 21 km from its mouth into the Adriatic Sea. The power plant uses a gross head of 110 m, and it was equipped with two generating units, so that at that time the total installed power plant capacity was 25.6 MW. In 1932, the second stage of the Kraljevac HPP was built. An additional two generating units were installed, rated at 20.8 MW each. With a total installed capacity of 67.2 MW and installed discharge of 80 m^3/s, the Kraljevac HPP was the largest hydroelectric power station in the Balkans.

Croatia

HPP Orlovac

HYDROPOWER PLANTS

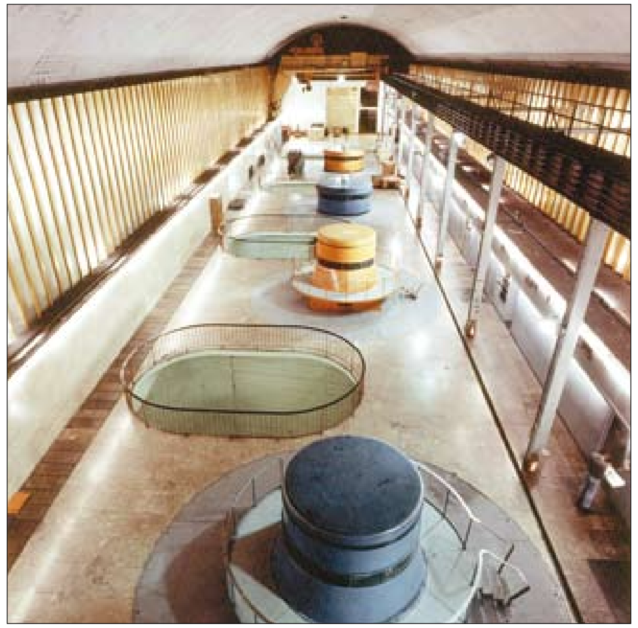
- **Multipurpose Hydropower System**
- Cetina River, Dalmatia
- 1908 - 1989
- The most important hydropower system in Croatia

The Cetina River Multipurpose Hydropower System is the most important of its kind in Croatia. The hydroelectric power plants comprising the Cetina System harness the waters of the Cetina River. From its spring to its outlet into the sea at Omiš, the river is 100.5 km long. The system also harnesses waters inflowing from the karst fields of the neighbouring Bosnia and Herzegovina, where a large reservoir has been built.

The Cetina River Multipurpose Hydropower System consists of five hydroelectric power plants: Peruća (1960), Orlovac (1974), Đale (1989), Zakučac (first stage 1961/ second stage 1980) and Kraljevac (first stage 1912 / second stage 1932) with a combined capacity of 810 MW and mean annual output of 2500 GWh. Construction of these plants comprised a number of complex and technically interesting structures. Two large reservoirs were built: Peruća (565 million m^3) and Buško Blato (800 million m^3), and another two reservoirs of smaller capacity. Two waste tunnels, 10 km-long each, and another 12.1 km tunnel were built. A penstock was installed with a diameter of 3.65-164 m, 1577 m long. The system also comprises two concrete and three embankment dams with a total capacity of about 4 million m^3, and four surface and one underground powerhouses.

In addition to its role in electricity generation, the Cetina River Multipurpose Hydropower System is important for flood control in the greater area and irrigation of agricultural land in the Sinjsko Polje. An additional function of the system is potable water supply to the settlements located along the Cetina River and several tourist resorts on the Adriatic coast. Construction of this system lasted from 1908 to 1989, and it considerably influenced the development of the Croatian energy sector and growth of the entire region along the Cetina River.

HPP Dale



HPP Zakučac, Powerhouse

Prančevići Dam

Croatia

BRIDGES

- **Bridge across the Lika River**
- Kosinj
- 1936
- Excellent integration into the landscape

The Lika River flows through the Ličko Polje area. At the narrowest point of the Ličko Polje, the Military Frontier long ago built a wooden bridge. Large rainfalls or snow melting quite frequently filled the river basin with currents which could not be accommodated. These currents very often washed out this wooden bridge. This happened in 1915, when the government decided to build a stone bridge instead. In 1925, the citizens of the town of Kosinje commissioned a design, and the government started construction of the stone bridge in 1928. The construction works were interrupted very soon after this, only to be continued in 1935 and finalised in 1936.

This stone bridge over the Lika River near Kosinje is one of the most successful bridges regarding shape and design. The river basin is spanned by three harmonious, semicircular openings, 18 m each, with circular recesses designed above the piers. Together with characteristic stone sleeves and offsets, it excellently blends into the overall line of the bridge. The bridge, with abutments, is 70 m long and 5.5 m wide. The stone used for construction was extracted very near the site itself, with concrete being used only for pier foundations and other minor works. The bridge was built according to the old Croatian bridge construction model. With its appearance, it can compete with the beauty of a number of famous bridges constructed much earlier.

Croatia

BUILDINGS

- **Meštrović Pavilion**
- Zagreb
- 1938
- Concept design by the renowned sculptor Ivan Meštrović

The Croatian Association of Artists “Strossmayer” reached an agreement in 1934 with the Committee to erect a monument to King Petar I, the Liberator. This monument was to be placed in Zagreb, but instead of a statue, it was decided that the monument should be in the form of a House of Artists, to be built in King Petar Square. The famous sculptor Ivan Meštrović was to do the conceptual design of the building. Detailed architectural plans, according to the Meštrović design, were done by the architects H. Bilinić and L. Horvat.

The Pavilion’s intended use and purpose changed throughout history. In 1944, three minarets and a fountain were added to the structure, turning it into a mosque. In the period 1945 to 1990, it served as a museum to the revolution and in 1990 it was finally returned to its original owner, the Croatian Association of Artists.

A modern rotunda of stereometric exactness, surrounded by a colonnade, forms an impressive portico. The interior space is structured for polyvalent programmes, and the large central hall was primarily assigned to sculpture exhibitions, while the first floor ring, balcony of the central hall and ground floor were assigned to exhibitions of other forms of visual art (painting, drawing, photography, design). The building represents, even at international level, an example of the synthesis of monumentalism and modernist asceticism, which holds to the tradition of various ideals from the Antique to the Neoclassicism of modern art. In its formal expression it belongs to the first period of modern architecture, which holds to a pluralism of styles (proto-rationalism, modern classicism, creative eclecticism). In the period when it was built it was a unique exhibition hall in Europe The dome is 19 m in diameter and is a compromise between the artist’s idea and the construction itself, where the building was originally designed as a lower central-type open building and not a closed space.

Croatia

DAMS

- **Peruća Dam and Reservoir**
- Peruća
- 1960
- The first reservoir in the world ever impounded in a karst area.
- During the war in 1993 the Peruća dam was blasted and seriously damaged

The Peruća Dam and Reservoir are located some 60 km NE from the city of Split and the Adriatic coast. Technically, both structures are globally significant. The Peruća Reservoir is the first reservoir ever impounded in a karst area. The Peruća Dam survived an intended destructive attack during the war in Croatia, to be rebuilt afterwards using the original engineering methods.

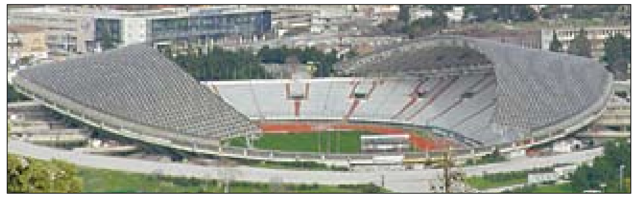
The Peruća Dam and Reservoir were constructed in the upstream stretch of the Cetina River in 1960. The reservoir capacity, area at maximum water level and length are 565 million m^3, 20 km^2 and 23 km, respectively. One of the primary issues affecting the success of the Peruća Reservoir project was how to impound the strong karst springs located forty to sixty meters below the reservoir level, particularly considering that the total yield of these springs accounted for more than a third of the water inflow into the reservoir. This problem was successfully resolved by the construction of a rockfill dam with a 64.5 m-high and 470 m-long central clay core, and a 1600 m-long and 100-200 m-deep grout curtain sealing the entire dam site.

During the war, the Yugoslav Army placed 20 to 30 tons of TNT in the grouting gallery of the Peruća Dam and blasted it on 28 January 1993. Although the grouting gallery and spillway structure were completely demolished and the clay core seriously damaged, the dam resisted and retained the 565 millions cubic meters of water which threatened the 20,000 inhabitants living downstream. Based on the results of quantitative and qualitative evaluation, the Peruća Dam was rebuilt by the construction of a 265 m-long and 15-55 m-deep plastic-concrete cut-off wall in the central clay core, and reconstruction of the left and right flanks with about a 100 m-long central core, and construction a new grouting gallery and spillway structure. Reconstruction of the Peruća Dam was a particularly difficult and complex engineering project, one which makes a significant contribution to the dam engineering discipline.

Croatia

BUILDINGS

- **City Stadium at Poljud**
- Split
- 1979
- Built for the Mediterranean Games



Poljud Stadium is situated in Split and was built for the needs of the Mediterranean Games. The shell-shaped stadium excellently blends into the surrounding Mediterranean views. Its original capacity was 50,000, but later reconstruction stages decreased this capacity to 35,000 seats. The structure can host football events as well as athletic competitions in all disciplines. At the time it was constructed, it respected all standards valid at the time, thus having standing room and seats for the spectators. The stadium influenced the architectural form of numerous stadiums worldwide, namely in Italy, Japan and Malaysia. It drew the attention of the professional public in the field of sports architecture. The roof structure is a combination of steel and semi-transparent Lexan polycarbonate sheets, roofing in the first construction stage only in the seating areas. The stadium also has auxiliary areas for the athletes.

Croatia

Krk Bridge

BRIDGES

- **Krk Bridge** (Krčki most)
- Mainland - Krk Island (near Rijeka)
- 1980
- Arch - main span 390 m
- The longest of this type in the world

This bridge between the mainland and the island of Krk is one of the most well known structures ever constructed in Croatia. The reason is the length of its main span, which exceeded the length of the longest reinforced concrete arch bridge by more than eighty meters.

The island of Krk is connected to the mainland by two arch bridges. The first, with its span of 390 m, traverses the 470 m canal between the mainland and St. Marko Island. The second bridge, with its 244 m span, crosses the canal between St. Marko Island and Krk Island. The bridge was completed in 1980.

Keeping in mind the position of the road grade above the sea and the span size which would correspond to this position in the gap between the mainland and St. Marko Island, it was impossible to construct an arch from shore to shore. Therefore, a unique foundation was designed with additional arms, the foundations of the slanting arms being executed in the sea. The cross-sectional shape of the arms depended on the execution method, by means of free cantilevering, which showed its extreme efficiency on this bridge with respect to the available equipment. This method of arch construction is performed using temporary cantilevers – consoles suspended on staying cables during construction work, which in turn transmit the force or tension through geotechnical anchors into the soil. Piers on the arch are constructed parallel to the cantilevers, and during construction work they form a truss structure together with the staying cables.

The structural bridge parts were constructed with the minimum, i.e. structurally acceptable, measurements, during a period when structural durability was of secondary importance. Namely, during the design stage, the problems of rapid dilapidation of concrete elements exposed to sea salt were little known. Because of this, practically since its completion, increased periodic maintenance is undertaken on the bridge, using various materials and technologies, this fact making the bridge recognisable in the world literature. Despite certain faults, the bridge even today represents an exceptional accomplishment, its appearance at the Kvarner Bay entrance testifying to the excellent engineering achievement.

Croatia

BUILDINGS

- **National and University Library - Old building**
- Zagreb
- 1913
- Secession architecture

The National and University Library building was constructed in 1913. Its primary role was to collect and preserve the written and printed cultural heritage, numbering approximately 110,000 pieces, which had been kept until that time in the Zagreb University Rectorial Building. This impressive Secession-style building was constructed in the Zagreb city centre to serve as a library building for a corpus of 500,000 books. It soon proved to be insufficient for the quantity of written and printed material, and the especially valuable collections it had to preserve.

Croatia

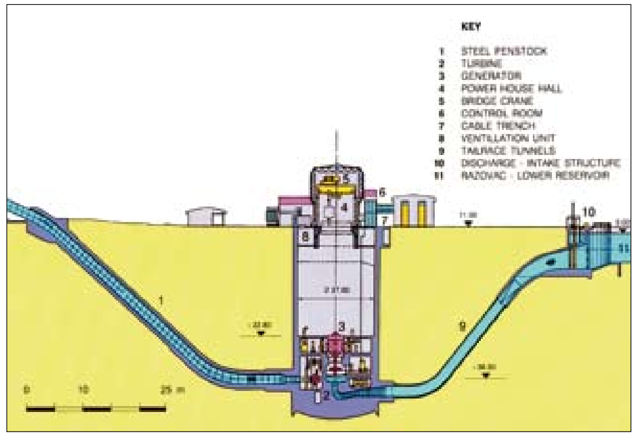
BUILDINGS

- **National and University Library - New building**
- Zagreb
- 1995
- Late-Modern architecture

Construction of the new National and University Library building started in 1988 and was completed in 1995. The library moved to the new building in the same year. This new library is a classic example of Late-Modern architecture. It was built as a library for approximately 2,500,000 volumes which had been stored in the old library building and numerous other locations throughout Croatia. This building is situated in Zagreb, along its main avenue, between the city centre and the Novi Zagreb area. Aside from its exterior lines, the interior of the building is very significant.

The National and University Library collects and preserves the written and printed cultural heritage of Croatia. The old library building now houses the Croatian National Archives.

Croatia



HYDROPOWER PLANTS

- **Velebit Pumped-Storage Power Plant**
- Gračačka Visoravan, Lika Region
- 1978 - 1985
- The penstock does not have expansion joints
- The powerhouse was built using sliding shaft technology

The Velebit Pumped-Storage Power Plant (PSPP) is a facility which harnesses the water of streams from the Gračačka Visoravan plateau in the SE Lika Region in Croatia. The plant is located at the altitude of between 550 and 700 m a.s.l., and separated from the sea by the Mt. Velebit massif. The Velebit PSPP powerhouse is located at 11.00 m a.s.l., by the Zrmanja River. Construction lasted between 1978 and 1985. The plant's installed discharge is 60 m^3/s through the turbines and 40 m^3/s in pump operation, and its capacity is 280 MW.

Considering the construction aspects of the project, an important feature is the steel penstock, with a diameter of 3.9 m to 3.25 m, 2,170 m long, which runs between a valve chamber and the powerhouse. The elevation difference between these two structures is 552 m. The penstock was installed without expansion joints, supported on sleeve bearings on 103 concrete supports and seven concrete anchor points, so statically it functions as a continuous beam.

Construction of the powerhouse was a special construction endeavour, since it was fitted with turbines and pumps at a depth of about 60 m below ground. The soil at the powerhouse site is marl. The powerhouse is 58 m high, with an internal diameter of 27 m and wall thickness 1.6 m, and it was built as a sliding powerhouse shaft. While excavation was taking place, the reinforced concrete shaft was gradually lowered under its dead weight, while on the surface, concrete was continually poured in a slip-form. To reduce friction between the shaft and the soil, a 20 cm gap was left on the outside, filled with a bentonite suspension.

Croatia

BRIDGES

- **Mirna Bridge**
- Near Novigrad, Istria across the Mirna River
- 2005
- Total length 1378 m

The Mirna Bridge crosses the Mirna River valley. It is situated on the western arm of the Istrian "Y" Motorway, in the northern part of Istria. The bridge is 1378 m long and its superstructure is a continuous girder superstructure.

The bridge's distinguishing mark is its foundations, executed on piles of average length of 62.5 m. Because of this, the aim during the design stage was to keep the total bridge mass as low as possible, with a span as large as possible, in order to keep the number of piers to a minimum. After analyses and calculations, a characteristic span length of 66.5 meters was adopted. The structural system of the bridge superstructure is a continuous girder over 22 fields in a horizontal and vertical curve. The cross-section consists of two longitudinal welded steel girders, 550 cm apart, composite with the concrete deck slab and connected with cross beams. The width of the viaduct in this first stage is 10.10 meters.

Croatia

BRIDGES

- **Bridge across the Rijeka Dubrovačka**
- Dubrovnik
- 2002
- The largest cable-stayed bridge in Croatia, main span 244 m

The Bridge across the Rijeka Dubrovačka (Dubrovnik River bay area) is situated at the eastern entrance to Dubrovnik, over the Ombla River canyon, almost immediately next to the mouth of the river, i.e. over the bay, crossing it at a height of 50 m. The bridge's micro-environment is exposed to sea, wind and earthquake influences, this fact also strongly influencing the design. This bridge does not have a recognisable or record span, but has drawn the attention of the professional public because of its unique assembly. Works on the bridge were complete in April 2002.

The bridge consists of a prestressed structure on the right (Split) shore and a cable-stayed structure on the left (Dubrovnik). Total bridge length between the abutment ends is 518 meters. The structure is made of two assemblies connected by a hinge joint in its central span. The prestressed approach on the west side starts with a beam of 87.4 m span with a box cross-section and continues with a cantilever console into the main span, 60 m in length. The cable-stayed assembly with a composite beam is 244 m long in the main opening and continues with an 80.7 m span at the end opening. The cable-stayed assembly consists of a composite beam, an "A"-shaped concrete pylon and high-strength structural steel sloping tendons. Lateral suspension was chosen in two levels, inclined toward each other, intersecting above the longitudinal bridge centerline on the pylon. This configuration offers the best structural and dynamic solution, since the pylon, beam and tendons give the impression of a grid suspended in the air. The pylon is 141.5 m high. the prestressed approach bridge offers very complex geometric forms, since its plan is partially in a transition curve and partially in a circular curve, finally transitioning in a straight to the main cable-stayed bridge. It consists of one beam girder fixed into the pier.

The bridge structure shows originality in its pronounced approach to functional and design values, its rational use of different construction materials, careful approach to durability and its interfusion between design and construction. These principles were optimally respected during construction of this bridge, which has become one of the prominent sights of this ancient city.

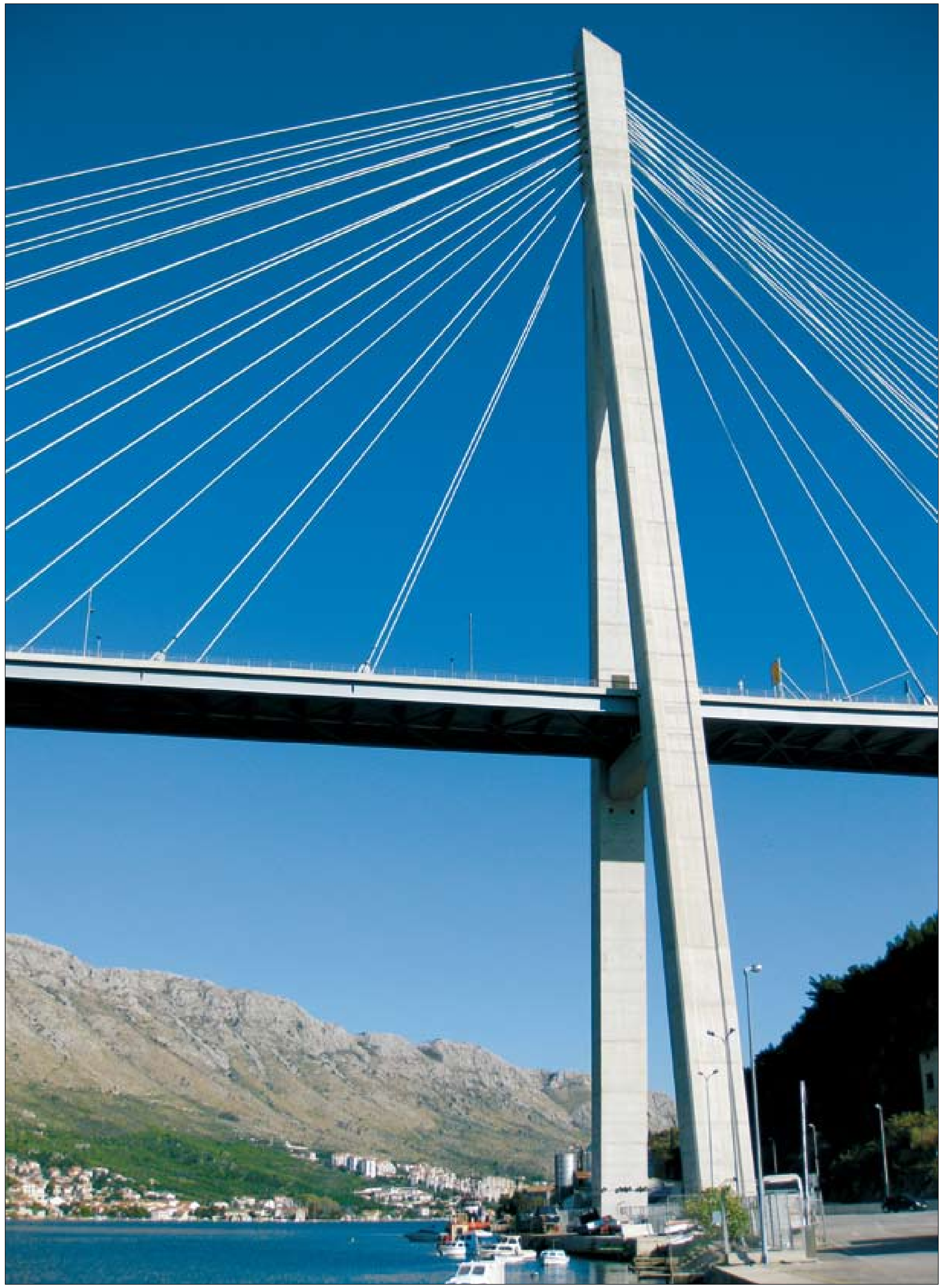


Photo: Gorazd Humar

Croatia

HIGHWAYS and ROADS

- **Zagreb - Split Motorway**
- 1970 - 2005
- Total length 393 km

The Zagreb - Split Motorway is the most significant motorway in Croatia (the so-called A1 motorway) connecting Zagreb to the Croatian south. At the same time it represents a part of two main international road corridors in Croatia: Pan-European corridor VB and the Adriatic - Ionian corridor.

The shape of the Croatian state territory is not practical in the traffic-operation sense, and this creates real difficulties for optimal road traffic connections, as the two main parts of the country, the Croatian Littoral and Pannonian parts, are divided by a massif. This complex spatial and traffic situation, as well as the relief, geological and hydro-geological characteristics of the motorway section from Karlovac to Split, influenced the choice of the ground and vertical motorway elements in some motorway sections.

The length of the motorway is 393 km and it was designed with two separate carriageways. Since the motorway route is a very demanding one, there are a large number of structures along the route, with special emphasis on the Mala Kapela Tunnel and the Sveti Rok Tunnel; the Drežnik, Modruš and Jezerane viaducts; and Dobra, Maslenica and Krka bridges. A total of 14 tunnels, 283 structures on and over the route, 16 special structures such as animal and game passages, special water protection and ecosystems have been built. A total of 25 interchanges were built on the motorway, as well as 25 roadside service facilities of various types, 10 traffic control centres, 3 primary toll gates and 18 toll gates at interchanges. Construction of the first 40 km started in 1970 and the remaining 90% of the route was constructed between the end of 1998 and the summer of 2005.

Krka Bridge, near Šibenik

Croatia

BRIDGES

- **Zagreb - Split Motorway**
- **Maslenica Bridge**
- Maslenica, near Zadar
- 1997
- Main span 200 m

The Maslenica Bridge is located on the Zagreb - Split Motorway near Zadar. In order to traverse the strait, a concrete arch with a 200 m span was designed, the arch being 65 m high. The arch cross-section is a box type, double cell with constant depth. The superstructure is continuous over 12 spans, each 350 m long, consisting of prestressed girders made monolithic with an in situ cast deck slab and transverse girders. The bridge is 20.4 m wide and 374.74 m long.

The bridge's design, details and construction materials were determined with respect to the aggressive influence of coastal environmental conditions and the seismic zone in which the bridge is situated. Due to these preconditions, very strict quality control of the construction materials and works was imposed, along with installation of sensors for monitoring the overall condition of the bridge, installation of a protective concrete cover ranging from 5.0 to 10.0 cm, and a polypropylene fibre protective net. High-impermeability concrete was used, with an admixture of organic inhibitors. This gives the bridge its sturdy look. The bridge arch was built using the free cantilever method, concreting small sections in a self-sliding cage. The arches were supported during construction by staying cables anchored into the rock massif with geotechnical anchors. The upper structure of the spandrel assembly consists of precast T-beams, subsequently prestressed. Preparation and prestressing of girders was done in a separate plant near the ridge. Installation of girders on a previously executed arch and piers was done with the help of a launching ramp: length 80.0 m, bearing capacity 100 tons. The bridge piers are symmetrical, executed in 5.0 m segments.

Croatia

Croatian Highway Tunnels

Contemporary construction of road tunnels in Croatia is very developed. This trend started with the construction of the Učka road tunnel in 1981. The Učka Tunnel is located on the Istrian "Y" Motorway, connecting Istria and the continental part of Croatia. At the time when the tunnel was commissioned, in 1981, with its 5062 m it was the longest road tunnel in Croatia.

The Učka Tunnel was the first tunnel to be constructed using the NATM method, all other road tunnels following this practice of construction using this same method. It is a two-way traffic tunnel with a longitudinal-type ventilation system.

Experience gained during construction of the Učka Tunnel was applied during construction of tunnels of the Zagreb - Split Motorway. Most significant among these tunnels are the Sveti Rok Tunnel and the Mala Kapela Tunnel. The Sveti Rok Tunnel, passing through the Velebit rock massif, was constructed in 2003. It is 5727 meters long and is the second-longest tunnel in Croatia. It was designed and constructed as a twin-tube tunnel. The first stage of construction, the right tunnel tube, is presently in operation. The second tunnel tube will be in operation by the summer of 2009.

The longest Croatian tunnel is the Mala Kapela Tunnel, with its 5780 meters. It passes through the Mala Kapela massif. Construction was completed in 2005. This tunnel, as well as the Sveti Rok Tunnel, was designed and constructed as a twin-tube tunnel. The first stage of construction, the right tunnel tube, is presently in operation. The second tunnel tube will be in operation by the summer of 2009.

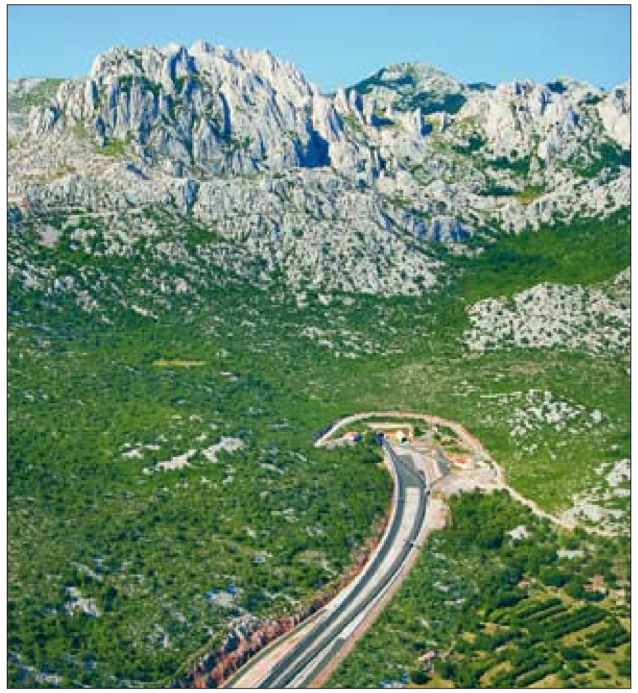
Tunnels constructed during this century are equipped in accordance with all recommendations and standards, with all sophisticated equipment required for control and management of traffic. The Brinje Tunnel was named the safest tunnel among the tunnels included in the Euro TAP testing project in 2007. It was completed in 2004, near Mala Kapela. The tunnel is 2540 meters long.

TUNNELS

- **Istrian "Y" Highway (Rijeka - Pula)**
- **Učka Tunnel**
- Near Opatija and Rijeka
- 1981
- Length of the tunnel 5062 m
- At the time the longest Croatian tunnel

TUNNELS

- **Zagreb - Split Motorway**
- **Sveti Rok Tunnel**
- Sveti Rok
- 2003
- Length of the tunnel 5727 m



TUNNELS

- **Zagreb - Split Highway**
- **Brinje Tunnel**
- Near Mala Kapela
- 2004
- The safest tunnel according the Euro TAP testing project in 2007

TUNNELS

- **Zagreb - Split Highway**
- **Mala Kapela Tunnel**
- Mala Kapela
- 2005
- The longest tunnel in Croatia

Croatia

BUILDINGS

- **Bale Sports Hall** (Sportska hala Bale)
- Bale (Valle in Italian), Istria
- 2008
- Awarded in the First World Festival of Architecture in Barcelona, 2008

Bale (Valle in Italian) is a small village on the Istrian Peninsula with a population of 1000 inhabitants and mostly agricultural. The project for a new sports hall was faced with the rich historical, cultural and social Mediterranean context. Therefore, any new architectural intervention had to have a respectful approach to the environment. Inspiration for the structure was found in the small traditional stone hut, "kažun", a small multifunctional building used as a shelter for shepherds, providing a cool environment in hot weather and insulating against the cold in the winter. At the First World Festival of Architecture held in Barcelona in 2008, the Bale Sports Hall was named the best in the Sport Structures category.

Cyprus

RAILWAYS

- **Cyprus Government Railways**
- In operation between 1905 - 1951
- The first Cyprus Railway
- Total length 122 km

It was the first railway for Cyprus which provided passenger and goods transport between cities during a period when very few vehicles were available on the island.

The Cyprus Government Railways operated a railway network in Cyprus from October 1905 to December 1951. The rail network had 2 ft 6 in (762 mm) gauge tracks which were supported by locally supplied timber sleepers. Photo 1 shows Engine No 1, which is currently on display in Famagusta. The speed of the train ranged between 32 and 48 km/h and the journey from Famagusta to Nicosia took about two hours with frequent stops in between due to large number of stations (one station every 3.2 km). Total length of the rail network was 122 km, of which 60 km was the part between the capital Nicosia and port city Famagusta. The port of Famagusta was the largest in Cyprus in the early 1900s so the railway was used to transport copper and chrome ore and asbestos to Famagusta for export.

Photo and text: Mehmet M. Kunt, Ph.D.,
Union of the Chambers of Cyprus Turkish Engineers and Architects, March 2009.

Cyprus

RESTORATION

- **Nicosia Municipal Market**
- Nicosia
- 1932
- With wooden trusses spanning 16 m

All photos made available by Department of Antiquities

The Municipal Market was divided into wholesale and retail areas until 2004. The wholesale area was vacated, subsequently rehabilitated and converted into a 'bandabulya' recreation area with cafe, bars and restaurants. The retail area is still partially operated as well as being restored and is still under repair.

The market place, which is geographically in the middle of Nicosia, still remains in its important location today with total area of 4600 m^2. The bazaar was completely open in the beginning, then took the shape it is today in 1932. Some parts of the building were built with clean-cut quadrangular sandstone as bearing walls, some with roughly cut stones and some parts with reinforced concrete members. Also, there are significant wooden trusses of 16 m spans strengthened by structural steel members during the restoration period.

Cyprus

DAMS

- **Kouris Dam**
- Kouris
- 1988
- The largest storage dam in Cyprus

Capacity: 115,000,000 cubic meters
Type: Earth fill dam
Height: 115 meters
Volume of embankment:
9,400,000 cubic meters

Kouris Dam is the largest storage dam in Cyprus. It is the major storage facility of the Southern Conveyor Project, which is the most important water development project in Cyprus. The dam was constructed using river gravel obtained from within the reservoir area and has a central clay core protected by well designed sand and gravel filters. The objective of the project is to collect and store surplus water from the western part of Cyprus and convey it to areas of demand in the coastal southern and eastern parts of Cyprus for both domestic water supply and irrigation.

Water is diverted from Dhiarizos River in the west through a 14 km tunnel to Kouris dam, which also collects water from its own watershed. From there the water is conveyed by gravity to the east through a ductile iron pipeline, 110 km long (diameters from 1400 mm to 800 mm).

Cyprus

TUNNELS

- **Limassol - Paphos Highway Tunnel**
- 1996
- The longest road tunnel in Cyprus

All photos by Mr. D. Rowland,
made available by Public Works Department

The Limassol – Paphos Highway passes through a twin – bore tunnel 980 m long. A stretch of 420 m of the tunnel is on a curved alignment and the remaining 560 m is on a straight line. The typical section of each bore of the tunnel has a diameter of 10.40 m with a clear height at the centre of 7.15 m. The final tunnel lining is made of reinforced concrete 60 cm thick. The tunnel was constructed using the drilling and blasting method. The total cost of the tunnel, which was completed and put into operation in 1996, was 20.5 million euros.

The tunnel is illuminated with an advanced modern system and the intensity of the light within the tunnel is automatically regulated based on the light intensity outside the tunnel.

Furthermore, for the safety of the drivers, a system of fresh air supply using special air ventilators and emergency telephones has been installed within the tunnel section.

Cyprus

BRIDGES

- **Petra tou Romiou Viaduct**
- 1999 - 2002
- Close to the famous Aphrodite’s Beach

Petra tou Romiou Viaduct is part of the new Limassol – Paphos highway. It consists of twin independent decks. Each deck comprises a 3.82 m high, single cell internally prestressed concrete box.

The length of the viaduct is 422.60 m long with 6 internal spans of 55.35 m and 2 end spans of 45.25 m. The viaduct was built using the Incremental Launching Method (ILM).

The max. height is 70 m over pier No. 4.

The foundation of the bridge piers consists of micro piles with in situ reinforced concrete caps (23.00 m x 11.50 m x 1.20 m).

The piers of the viaduct are in situ hollow box columns and the height varies from 15.00 m to 58.00 m.

The design consultants for the Petra tou Romiou Viaduct were EISPA ESTUDIO DE INGENIERAY PROYECTOS from Spain.

The construction of the viaduct started in 1999 and was completed in 2002.

Photo by Mr. D. Rowland, made available by Public Works Department

Cyprus

All photos by Mr. D. Rowland, made available by Public Works Department

HIGHWAYS and ROADS

- **Limassol - Paphos Highway**
- 1993 - 2001
- Total length 55 km

The new Limassol – Paphos Highway is a major artery of Cyprus and connects the Western part of the Island with the other districts. It has a total length of 55 km. The construction works started in February 1993 and were completed in 2001.

It has a dual carriage way of 7.0 m width and 3.5 m of hard shoulder with a concrete median separator of 3.00 m width.

The Highway runs along hilly terrain and includes 10 bridges/viaducts and a twin tunnel 1 km long. Some of the bridges have a height of nearly 60 m.

The construction method of the bridges used with the latest technology (segmental construction).

The total cost of the highway was over € 187,000,000.

Cyprus

RESTORATION

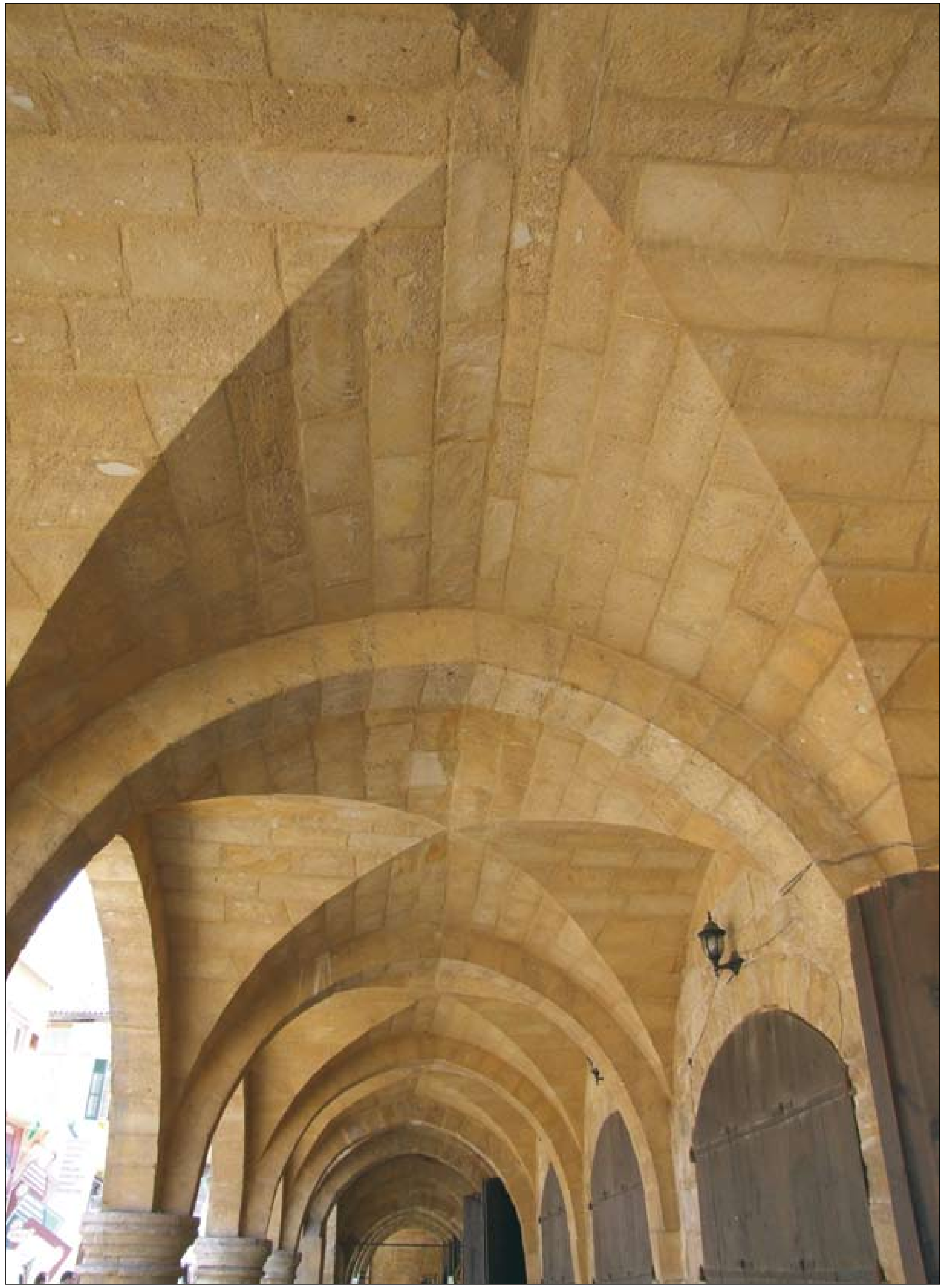
- **Buyuk Khan (Big Inn)**
- Nicosia
- 1572 - 2002
- Made of sandstone blocks
- Today a centre of art and traditional handicrafts

All photos by Turgut Oztuner

Buyuk Khan was built in 1572 by Ottomans and is the biggest khan of its type still existing in Nicosia among the known 18 of its kind. The building structure consists of sandstone bearing walls and the roof is of great significance with cross-arch-vaults. The two storey building with a rectangular plan of 50.67 m x 45.45 m has an inner courtyard of 27.28 m x 26.21 m surrounded by 68 rooms and 10 shops. In the courtyard there is a picturesque octagonal tower used as mesdjit, with a picturesque fountain below.

The building had been mostly the place for the merchants to stay for the night in the late 1900s and was used as Central Prison Building at the beginning of the twenteeth century. The building was vacated in 1962 due to health and structural problems. Eventually in 1995 a succesfull attempt was made and the restoration and renovation was implemented in 2002.

Today, the building is used as the centre of art and traditional handicrafts with traditional coffee shops and cafe.



Finland

RESTORATION

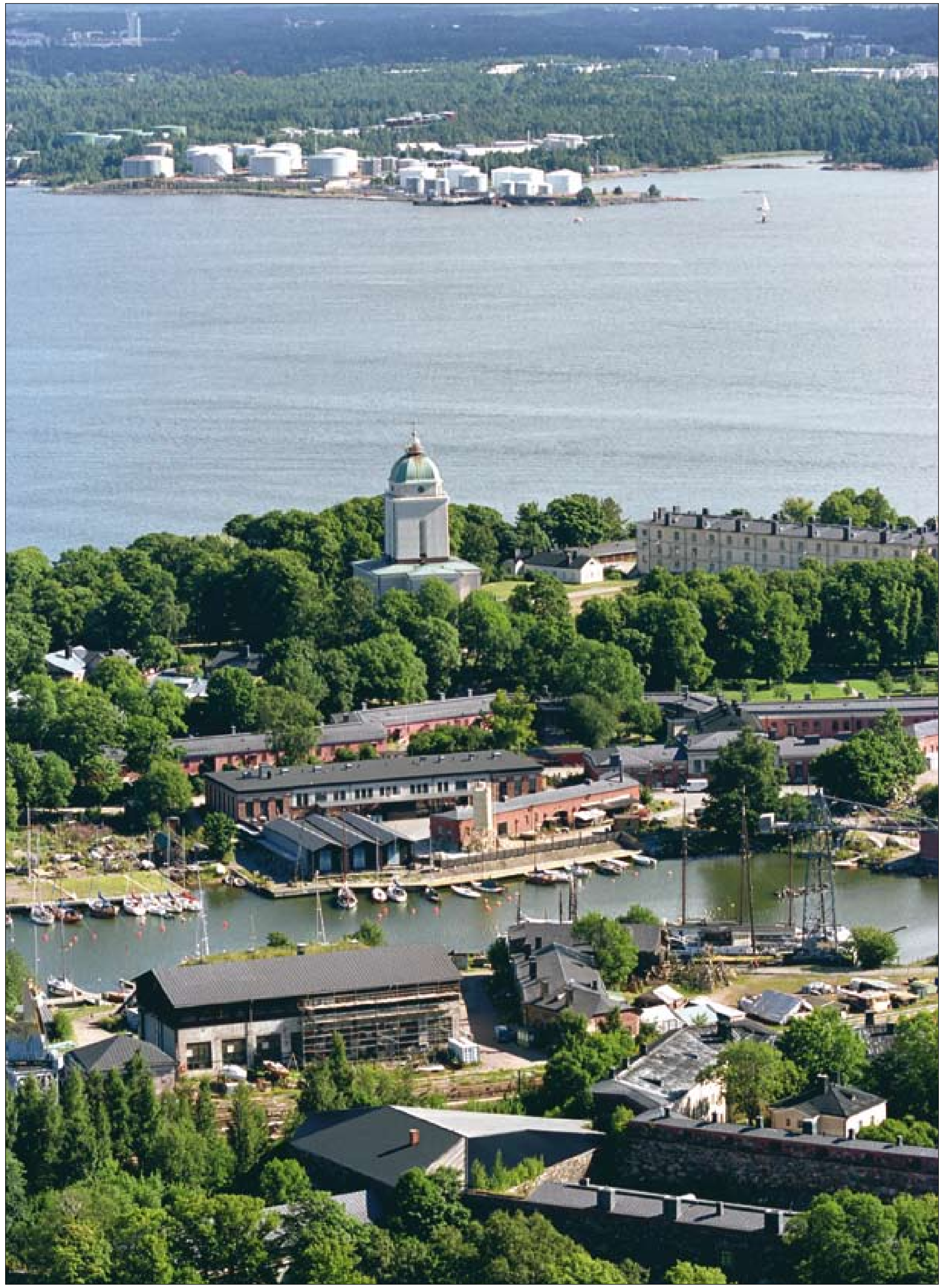
- **Suomenlinna Sea Fortress**
- Helsinki
- 18th century
- Included in UNESCO's World Heritage List (1991)
- A popular tourist attraction

Suomenlinna is a major monument of European military architecture. The construction of the sea fortress on the islands just off Helsinki in the middle of the 18th century was the most extensive building project in Finland during Swedish rule. When it was complete, its military shipyard was one of the biggest dry docks in the world and centers of know-how at that time. At the end of Swedish rule the fortress was being compared with the maritime fortifications at Gibraltar.

The 250-year-old fortress, which has been preserved intact because of its military use, is today part of the world heritage. In 1991 it was included in UNESCO's World Heritage List.

Suomenlinna is one of Finland's most popular tourist attractions, with over 600,000 visitors annually. At the same time it is a suburb of Helsinki, with 850 people living there. The old buildings are in use as homes, offices, maintenance buildings and service points. The buildings are constantly renovated. A dry dock built in the 18th century is still in use as a place for restoring old wooden sailing boats.

The environment in Suomenlinna is a mixture of Finnish archipelago nature and flora planted over the centuries. Many migrating birds stop in Suomenlinna and some, such as swans and barnacle geese, also nest on the islands.



Finland

CANALS

- **Saimaa Canal**
- Vuoksi watercourse
- 1856
- The Historic Canal

The Saimaa Canal (Finnish: Saimaan kanava) is a transportation canal that connects Lake Saimaa with the Gulf of Finland near Vyborg, Russia. The canal was built from 1845 to 1856. It was overhauled and widened in 1963-1968.

A system of inland waterways and canals in the 120 interconnected lakes of the south-central and south-east part of Finland (Finnish Lakeland) are reached through the canal. The length of deep channels in Lake Saimaa (with an authorized draught of 4.2 m) is 814 km. The deep channels extend to Kuopio in Central Finland.

Dimensions of the canal are:

Length: 42.9 kilometers
(19.6 km in Russia and 23.3 km in Finland)
Width: From 34 to 55 meters
Total rise from the Gulf of Finland to Lake Saimaa: 75.7 meters
The maximum dimensions allowed for a ship transiting the canal are:

- Length: 82.0 meters
- Beam (width): 12.2 meters
- Draft: 4.35 meters
- Height of mast: 24.5 meters

There are three locks in the Finnish part of the canal and another five locks situated on the Russian side of the border. The canal crosses 12 motor vehicles bridges and two railroad bridges.

Finland

BRIDGES

- **Hämeensilta**
- Tampere (Tammerkoski Rapids)
- 1929
- Engineer: L. Eriksson

The Hämeensilta Bridge crosses the strong Tammerkoski Rapids and connects two centres of the City of Tampere. There has been a bridge on the same site since the 16th century and the current one is the eighth one in a row.

The latest Hämeensilta Bridge is a typical single arch concrete bridge. It's span is 40 meters long and it is over 28 meters wide. Its surface is upholstered with red granite that makes the bridge look like a massive stone bridge rather than a light reinforced concrete structure. The bridge has unique decoration; there are two bronze statues at both ends of the bridge. The "Maiden of Finland", "The Merchant", "The Hunter" and "Tax Collector" were made by famous Finnish sculptor Wäinö Aaltonen.

Finland

TOWERS

- **Tower of the Helsinki Olympic Stadium**
- Helsinki
- 1934 - 1938
- The largest stadium in Finland
- Height of the tower 72 m

The Helsinki Olympic Stadium (in Finnish and Swedish: Olympiastadion) is the largest stadium in Finland. Nowadays it is mainly used for sports events and big concerts.

The stadium is best known for being the center of activities in the 1952 Summer Olympics. It was built, however, to host the 1940 Summer Olympics, which were moved from Tokyo to Helsinki before being cancelled due to World War II. The stadium was also the venue for the first World Athletics Championships in 1983 as well as for the 2005 World Championships in Athletics. It is also the home stadium of Finland's national football team.

Construction of the Olympic Stadium began in 1934 and was completed in 1938. The stadium was completely modernised in 1990-1994 and was also renovated just before the 2005 World Championships in Athletics. Its spectator capacity was at its maximum during the 1952 Summer Olympics with over 70,000 seats. Nowadays the stadium has 40,000 seats.

The tower of the stadium, a distinct landmark with a height of 72 meters, is open for visitors and offers impressive views over Helsinki.

Finland

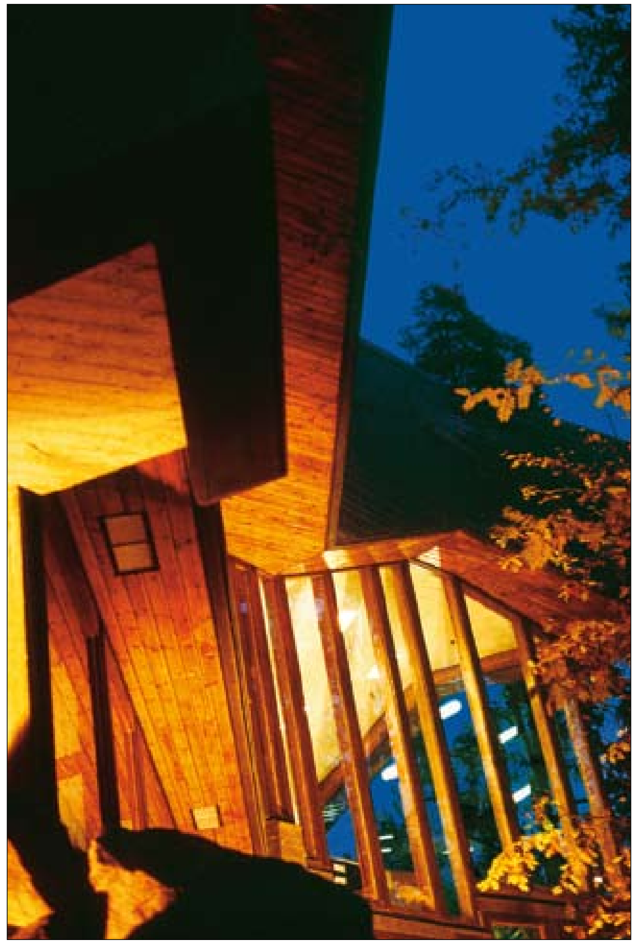
BUILDINGS

- **Dipoli Congress Center**
- Otaniemi, Espoo
- 1966
- Architects: Reima and Raili Pietilä
- Today a training centre of the University

Dipoli is a conference center located in Otaniemi, Espoo, Finland. It is part of the campus area of Helsinki University of Technology (TKK).

When TKK moved from Helsinki to Espoo in the early 1960s, a design contest was held for a new building of the Student Union of TKK. The contest was won by famous architects Reima and Raili Pietilä, and their 1961 design was used as the blueprint for the Dipoli building. Work began in 1965, and the building was ready for use in 1966. It was named 'the second Poli', the second building of the polytechnic students

In 1993 the building was transformed into a training centre of the university. Although the Student Union has sold the property due to high maintenance costs, it is still regularly used for conventions, congresses and student parties.



Finland

Temppeliaukio Church

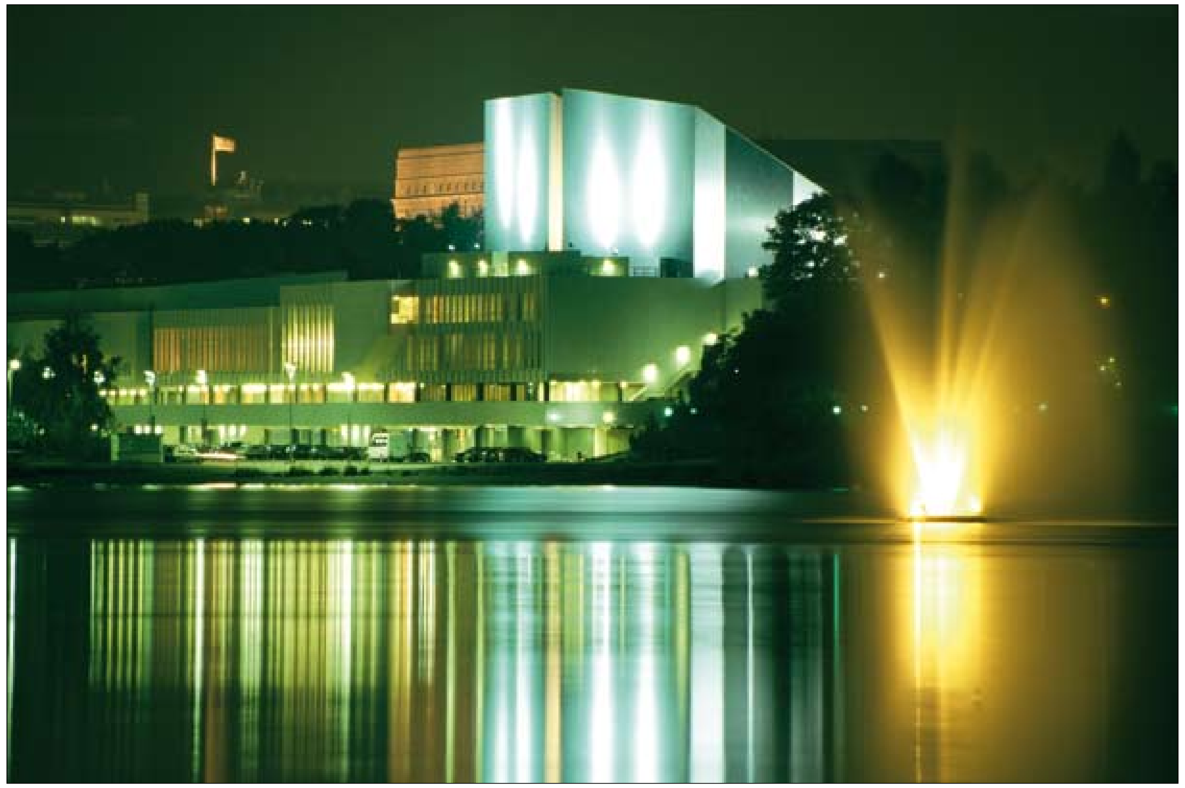
RELIGIOUS BUILDINGS

- **Temppeliaukio Church**
- Helsinki
- 1969
- Also known as the Church of the Rock
- Quarried out of the natural bedrock
- Over 15 million visitors by the year 2000

Temppeliaukio Church was built in 1968-1969. It was designed by the architect brothers Timo and Tuomo Suomalainen. The church is quarried out of the natural bedrock and its interior walls are created naturally by the rock, therefore it is also known as the Church of the Rock. Natural light brightens the inside through 180 glass strips between the dome and the wall. The church is often used for concerts because of its excellent acoustics.

Temppeliaukio Church is one of the most famous tourist attractions in Helsinki; as of the year 2000 there have been over 15 million visitors. The Church is the only Finnish building included in the Italian encyclopedia I Cento Monumenti, the Monuments of the World.

Finland



BUILDINGS

- **Finlandia Hall**
- Helsinki
- 1971-1975
- The leading congress and concert venue in Helsinki
- Designed by architect Alvar Aalto

Finlandia Hall is the leading congress and concert venue in Helsinki. It was designed by the world-famous Finnish architect Alvar Aalto and is visited by thousands of people a year from all over the world.

The main idea of Finlandia Hall is its tower-shaped part and inclined roof rising over the whole structure. The idea of this shape was to improve the acoustics of the concert hall by providing a resonance area overhead. It is unfortunate that this attempt proved in practice to be partially unsuccessful. Yet, the result still provides us with the visual satisfaction of its monumental exterior.

The interior also provides typical examples of many of Aalto's hallmarks and motifs. The large asymmetrical auditorium is a simplified version of Aalto's most magnificent auditorium in the Great Opera House in Essen, Germany. Between this closed hall for 1,700 people and the small auditorium for 340 people lies the foyer, which is like an open landscape. This foyer layout is continued into the congress wing where the most conspicuous architectural feature is the wall which curves inwards in small sections.

The entire building's volume is 125,140 m^3 and its floor area is 18,157 m^2.

Finland

BRIDGES

- **Jätkänkynttilä**
- Rovaniemi (Ounaskoski Rapids)
- 1989
- Engineer: E. Järvenpää

The Jätkänkynttilä (Lumberjack's Candle) Bridge lies on the Arctic Circle where it connects the Ounasvaara arctic hill area to the city centre in Rovaniemi, the capital of Finnish Lapland. This unsymmetrical cable bridge with one pylon was the first cable-stayed road bridge in Finland. The pylon is composed of two cylindrical columns made of reinforced concrete. Both columns have a diameter of 2.3 meters and the higher one reaches 47 meters up from the deck.

Total length of the bridge is 320 meters. The main span is 126 meters long and four other spans are 42 meters each. The bridge is exceptionally wide, almost 26 meters, taking account that the steel and concrete deck is supported only from the middle of the bridge's cross section. The deck's case body structure made this possible.

BRIDGES

- **Saamensilta**
- Utsjoki (Teno River)
- 1993
- Engineer: Suunnittelukortes Ltd Johs Holt A/S

Sami Bridge (in Norwegian Samelandsbrua, in Finnish Saamen silta) crosses the Teno River between Finnmark county in Norway and Utsjoki in Finland. This world's most northern cable-stayed bridge is 300 metres long, and the main span is 155 metres. The smaller spans are 35, 75 and 35 meters, respectively. Its reinforced concrete deck is 10.5 meters wide. European route E75 runs across the bridge.

The four pylons of the bridge are composed of cylindrical steel columns filled with concrete. Parallel diagonal steel cables are galvanized and protected with polyethylene tubes filled with grease in order to prevent corrosion.

One of the main design criteria was the mean water level during summer time. The main span was designed to enable as free passage as possibly for the migrating salmon. The bridge's conical supports are designed to cope with the fierce ice melting process on the Teno River.

Finland

BRIDGES

- **Saimaansilta**
- Puumala (Puumalansalmi)
- 1995
- Engineer: K. Santala

The Saimaa Bridge replaced the last ferry boat connection on the Finnish main road network when it was built across the Puumala Strait in 1995.

The bridge is a composite girder bridge with a main span of 140 meters. Total length of the bridge is 781 meters. An approximately 40 meter high lift tower gives the bridge its particular characteristics. The lift carries pedestrians and cyclists from waterfront pier to the bridge deck over 30 meters higher.

Over the water, the height of the steel structure varies between 1.5 to 6 meters, which is the tallest welded I-beam in Finnish bridges. Because of the geometry of the bridge, all steel structures were installed by lifting the segments into place. The heaviest segment was 105 meters long and weighed 580 tons. Work was especially challenging because of strong winds and water flow with floating ice.

BRIDGES

- **Raippaluodon silta**
- Mustasaari (Raippaluoto Maritime)
- 1997
- Engineer: P. Pulkkinen

Raippaluoto (Replot) Bridge is the longest bridge in Finland. It joins the Raippaluoto Archipelago to the mainland, replacing the ferries used previously, serving 2,200 island residents daily and making it easy for tourists to visit the outlying islands. Today the bridge is also a popular tourist attraction.

The bridge was opened in August 1997. It has a length of 1,045 m and is carried by pylons 82 meters high. The total number of spans is 12; the middle span is 250 meters wide and gives a vertical clearance of 26 meters above the sea level. Other spans vary between 50 and 95 meters.

Geological conditions on the site were and still are very difficult. The sediment on a sea bottom is so-called water moraine, typical with alternating compactness and granular size. Since the last Ice Age, land has risen on the Gulf of Bothnia's area and it still does, at approx. 8 mm per year. Lowering of the water levels cause strong currents that erode and transport sediments together with hard ice conditions. All this had to be taken into account when designing the foundations of the bridge.

Finland

BRIDGES

- **Vihantasalmi Bridge**
- Mäntyharju
- 1999
- Engineer: T. Rantakokko

The Vihantasalmi Bridge crosses Vihansalmi Strait on Highway 5, which runs from Helsinki to Finland's famous Lake District. The bridge is well known, since it is the largest wooden highway bridge on main roads in the world.

The bridge was constructed according to the winning proposal of a design competition. There are three wooden trusses with 42 meters span each. The bridge deck is 11.75 meters wide. The diagonal trusses are made of glue-laminated beams between which there are pull-rods made of steel. The wooden structure rises 22 meters above the bridge's reinforced concrete deck. The concrete deck and wooden girders act as one composite structure since they are joined with steel bars. The bridge bears on concrete stands that are covered with sheets of granite.

Finland

BUILDINGS

- **FMO Tapiola**
- Espoo
- 2005
- Five-stories (incl. foundation); floor space 13,300 m^2

FMO Tapiola was constructed as headquarters of The Tapiola Insurance Company. Today it is the tallest wooden office building in Europe. It's architectural design was made by Helin & Co Architects and structural design by the structural design engineering company Suunnittelukortes.

FMO Tapiola incorporates several innovations and product applications developed by Metsäliitto Wood Products Industry (Finnforest). The five-storey building's versatile use of wood has been combined with stone, glass and steel to add sophistication to its modern looks. The building has a frame of Kerto columns and beams and there are boxed slabs in intermediate floors. The façade is made of split gluelam beams.

FMO Tapiola Building was the winner of Finland's most prestigious wood architectural competition, the Wood Award in 2006. FMO Tapiola also shared second place in the Finnish Civil Engineering Work of the Year Competition (RIL Prize) in 2006. The RIL Prize is one of the most prestigious civil engineering awards in Finland and is given annually by the Association of Finnish Civil Engineers RIL.

France

Photo: Georges Pilot

BRIDGES

- **Jacques V Gabriel Bridge**
- Blois, Loir et Cher
- 1724
- Jacques V Gabriel - The first "Ingénieur des Ponts et Chaussées (1717)

This stone bridge is built on the Loire River. For a long time, it was the only bridge in this town, on a main royal road from Paris to the southwestern provinces and to Spain. This arch bridge is 283 m long, comprising 11 spans whose length varies between 16.55 m and 26.30 m. Its construction used a new scaffolding technology: two intermediate piers are larger that the others, playing the role of local abutment. The bridge suffered during wars: several vaults were destroyed, but reconstructed later.

Jacques V Gabriel (1667-1742) was the architect and engineer of this bridge, with Jean-Baptise de Régemortes. Gabriel was appointed the first Ingénieur des Ponts et Chaussées in 1717. He was involved in the design or construction of many monuments and sites, for example the Assemblée Nationale building in Paris, Saint-Louis Cathedral in La Rochelle and Place de la Bourse in Bordeaux. Jean-Baptiste Régemortes, a military engineer, is known for works on the Ligne fortifiée de Wissembourg and Canal des Français in Alsace, also the Canal du Loing, connected to the Seine River in the south of Paris.

Photo: Georges Pilot

BRIDGES

- **Concorde Bridge** (Pont de la Concorde)
- Paris, Seine River
- 1790
- Built by Jean-Rodolphe Perronet
- Very slender piers

This stone bridge spans the Seine River in Paris, linking the Place de la Concorde (north bank) and Quai d'Orsay, Quai Anatole France and Boulevard Saint-Germain (south bank). It is 153 m long, comprising 5 circular arches with 25 to 35 m spans. It is representative of concepts developed by Jean-Rodolphe Perronet, the engineer in charge of the project: instead of considering that each pier must work as an arch abutment, stable in and of itself, all arches were built at the same time, allowing slender piers. Construction of the bridge was made using stone from the demolition of the Bastille jail during the Revolution.

Jean-Rodolphe Perronet (1708-1794) was the designer of many roads, bridges and canals. He was appointed as the first Director of the Ecole Nationale des Ponts et Chaussées from 1747 to 1794 (initially the Bureau des dessinateurs du Roi, later the Ecole Royale des Ponts et Chaussées in 1775). Due to congested traffic, the bridge was widened on both sides in 1932. The engineers in charge of this work, Deval and Malet, preserved the architecture of the original bridge.

Photos: Gorazd Humar

France

All photos: Gorazd Humar

BRIDGES

- **Sully Bridge** (Pont de Sully)
- Paris, Seine River
- 1876
- Cast iron bridge

This cast iron bridge was built to cross the Seine River in Paris, and it links Boulevard Henri IV (north bank) and Boulevard Saint-Germain (south bank). It comprises two separate branches, each bearing on the eastern tip of the Île Saint-Louis and was named after Maximilien de Béthunes, Duke of Sully, minister of King Henri IV.

The main bridge (in the picture) is one of the rare cast iron road bridges still existing in France. It is 141 m long, with a central arch 49 m long and two side spans 46 m long.

The engineers in charge of the Sully Bridge project were Gustave Brosselin and Paul Vaudray. Paul Vaudray was involved in other Paris bridges: Pont de l'Alma (now removed), Pont-au-Change, Pont des Invalides and Pont Saint-Michel.

France

Owner of the photograph: Mr. Jean-Marie Calbet

TOWERS

- **Cordouan Lighthouse**
- Le Verdon (Gironde)
- 1790
- Oldest lighthouse in France
- Historical monument

Cordouan Lighthouse, the oldest in France, is located 7 km off shore at the entrance of the Gironde estuary in the southwest of France. It governs ship traffic in the estuary, up to Bordeaux Harbour. The first lighthouse on this site was installed at the end of 16th century and reconstructed in 1724 after sustaining damage; finally, 30 m of extra height was added by the Navy engineer Joseph Teulère. It features stone masonry construction, 67.5 m high, built on a 41.65 m diameter tower. The lighthouse tower comprises 6 floors, with the King Apartment, the Chapel, the Salle des Girondins, operational rooms and finally the light. Cordouan Lighthouse was the first to be equipped with Fresnel lenses, in 1823, modified in 1854 and still operating today. Cordouan Lighthouse is registered as a historical monument.

Photo: Robert Cortright, USA

BRIDGES

- **Garabit Viaduct** (Le Viaduc de Garabit)
- Loubaresse (Cantal)
- 1884
- Masterpiece of Gustave Eiffel
- Main span 165 m
- At the time the highest in the world

Garabit Viaduct is made of iron, built on the Saint-Flour/Marvejols line designed by Léon Boyer in 1877. Located in the mountainous Massif Central, the viaduct is constructed 120 m over the Truyère River. It is clearly a masterpiece of Gustave Eiffel. The viaduct is 565 m long, comprising the main iron bridge, 448 m long, and two stone approach bridges, 46 and 71 m long. The wrought iron viaduct is a remarkable work, with a main span 165 m long, supported by a parabolic arch with two hinges. The deck, a truss beam, is supported by iron pylons up to 80 m high, bearing on masonry abutments and foundations. Constructed a few years after the Maria-Pia/Douro Viaduct (Portugal), Garabit Viaduct was the highest in the world. It is registered as a historical monument.

The main engineer was Maurice Koechlin, also involved in New York's Statue of Liberty and designer of the Eiffel Tower. Gustave Eiffel, an engineer from the Ecole Centrale in Paris, was the designer of Garabit Viaduct, as well as the contractor (Eiffel et Compagnie). He designed, managed and constructed a considerable number of iron and steel works, included the well-known Eiffel Tower.

France

TOWERS

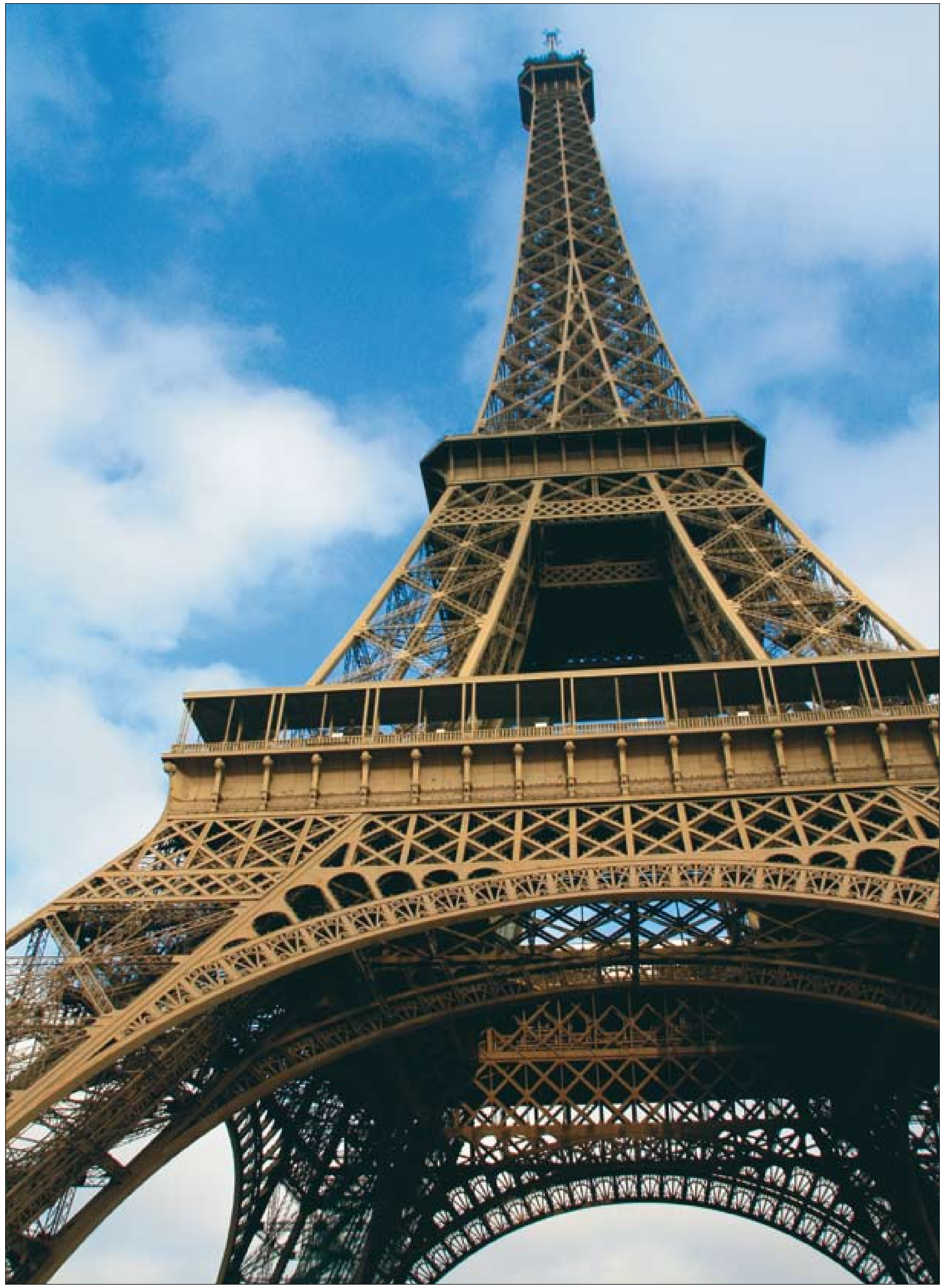
- **Eiffel Tower** (La Tour Eiffel)
- Paris
- 1889
- For 41 years the tallest structure in the world
- Historical monument

All photos: Gorazd Humar

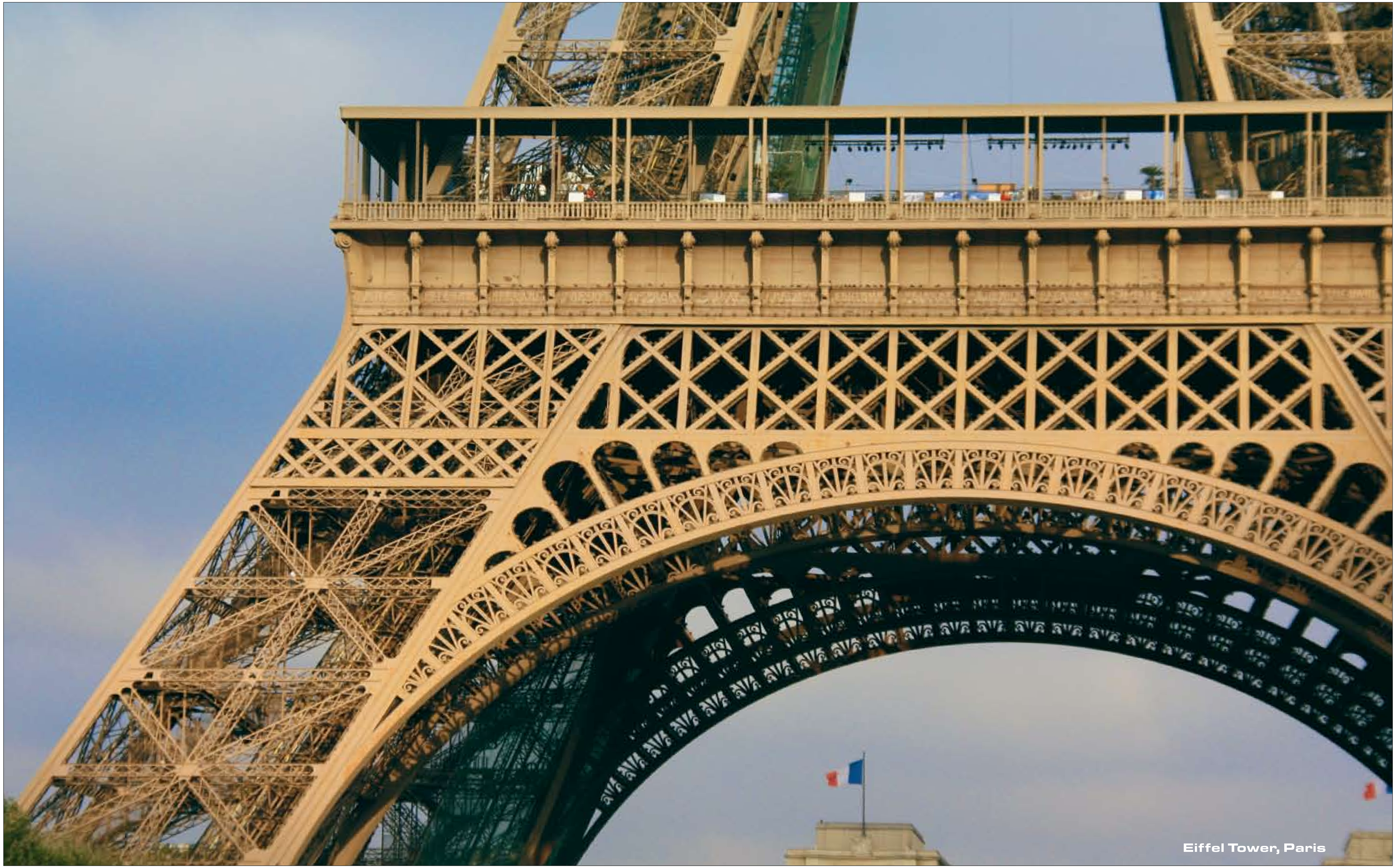
The Eiffel Tower, the main landmark in Paris, was built on the Champ de Mars, beside the Seine River, on the occasion of the Worlds Fair organised in Paris in 1899. At the time of its construction the tower, at 300.65 m high, was the tallest structure in the world, until the completion of the Chrysler Building in New York (1930). With the modern antenna, it is now 325 m high. The shape of the Eiffel Tower was determined mathematically, considering wind forces on the tower. The tower comprises 3 platforms: at 91 m, 149 m and 309 m, and its base is contained, at ground level, within a 125 m x 125 m square. It is supported by piers bearing on foundations through 25 m^2 concrete bases, 4 m high. The structure is constructed in wrought iron. With a weight of 7,000 tons, it comprises 18,000 pieces assembled with 2,500,000 rivets.

The main engineers involved were Maurice Koechlin and Emile Nouguier, and the architect Charles Sauvestre contributed to the design. Gustave Eiffel was the builder of the tower. Maurice Koechlin (1856-1946), initial designer of the tower, was an engineer from the ETHZ in Zurich. He was involved in the design of many bridges and monuments, including the Garabit Viaduct, La Mulatière Bridge in Lyon and the structure of the Statue of Liberty in New York. Maurice Nouguier (1840-1898) was an engineer from the Ecole des Mines in Paris. He was involved in many bridge designs, in France (Cubzac Road Viaduct, La Tardes Rail Viaduct and Garabit Viaduct) and other countries in Europe (Margit Bridge in Budapest, Douro Viaduct in Portugal and Tage Bridge in Spain). Charles Sauvestre (1874-1919) was an architect from the Ecole Spéciale d'Architecture, involved in many projects, for example the Chocolaterie Menier in Noisiel. Gustave Eiffel was an engineer from the Ecole Centrale in Paris. He designed, managed and constructed a considerable number of iron and steel works.

Eiffel Tower, Paris



Eiffel Tower, Paris



Eiffel Tower, Paris

France

Photo: Georges Pilot

BRIDGES

- **Alexandre III Bridge**
  (Pont d'Alexandre III)
- Paris, Seine River
- 1900
- Largest bridge in Paris
- Historical monument

The Alexandre III Bridge spans the Seine River, connecting the Grand Palais and Petit Palais area on the right bank and the Esplanade des Invalides on the left bank: all together an outstanding perspective in Paris. This bridge was inaugurated in 1900 for the Paris Universal International Exhibition along with the Grand Palais and Petit Palais. It is 140 m long and 40 m wide, making it the largest bridge in Paris, with a steel arch 109 m long and 6 m high: with an aspect ratio of 1/17, it was remarkable at the time of construction. The arch comprises 15 parallel arcs with 3 hinges. The arcs are constructed with steel segments smelted and moulded in a factory, finally bolted together on the jobsite.

The bridge was named Alexandre III after the conclusion of the Franco-Russian Alliance in 1892 and is considered the most beautiful bridge in Paris. It is registered as a historical monument. The engineers were Jean Résal and Amédée d'Alby. Jean Résal (1854-1919), an engineer from the Ecole Nationale des Ponts et Chaussées, was considered the best iron and steel designer at the end of the 19th century (Mirabeau Bridge, Debilly Footbridge in Paris).

Photo: Gorazd Humar

Photo granted by Freyssinet

Alexandre III Bridge

Photo: courtesy of Freyssinet

France

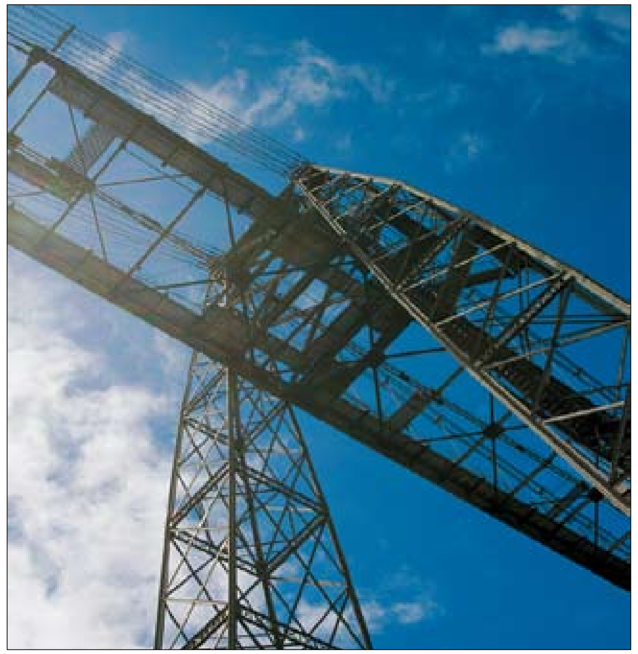


Photo: Georges Pilot

BRIDGES

- **Martrou Transporter Bridge**
- Rochefort-sur-Mer
- 1900
- Historical monument

Martrou Transporter Bridge traverses the Charente River, downstream of Rochefort-sur-Mer, in order to allow ships from the harbour and shipyard to navigate the river. It is a steel bridge comprising a deck 175 m long, with a main span of 140 m. The deck is supported, as a suspension bridge, by two truss pylons 66 m high, so the free height above water is 50 m. The cabin is suspended by cables to a 'ferry' which circulates on rails belonging to the deck. At the time of construction, a 14-ton load could be carried by the cabin. The deck and the suspension system were replaced and modified in 1934, allowing a 16 ton load until 1967. Finally, after heavy maintenance, the bridge was reopened in 1994 and is now used for pedestrian and bike transport. Martrou Transporter Bridge is the last one in service in France and a rare one in Europe. This bridge was built by Ferdinand Arnodin (1845-1924), basically a suspension bridge inspector who was involved in the design or construction of five other transporter bridges in France as well as several others in Spain and the UK.

Photo: Georges Pilot

France

BUILDINGS

- **Le Grand Palais**
- Paris
- 1900
- Historical monument


Photo: Georges Pilot

The Grand Palais was part of a large urban project launched for the 1900 Paris Universal International Exhibition. This project aimed at opening a new perspective (now Avenue Winston Churchill) between Avenue des Champs Elysées and the Esplanade des Invalides. The Alexandre III Bridge, built at the same time, links the two banks of the Seine River. The Grand Palais, facing the Petit Palais, has an impressive entrance at the centre of a 240-m-wide façade. The Grand Palais has an H-shaped plan that allowed four architects to compose a collective style for this building (Henri Delagne, Charles Girault, Albert Louvet and Albert Thomas). It comprises stone walls and columns, a huge steel structure and a braod glass roof: one of the most interesting pieces of art is the Great Dôme, 40 m high. Slabs and beams in reinforced concrete were constructed by François Hennebique. The Grand Palais was used extensively for a number of successful exhibitions.

In 1993, a bolt fell from the roof and revealed severe structural disturbances due to differential settlement of the foundation: the building bears on wood piles, decayed due to lowering of the water table. Major restoration work was initiated (foundations, structure, glass and paintings), allowing the reopening of the Grand Palais in 2005. Now, the Grand Palais is used by Le Palais de la Découverte, by the National Art Galleries, and for large cultural and business exhibitions. The Grand Palais is the only building from this period and in this style still existing in the world.

BUILDINGS

- **Hennebique Building**
- Paris
- 1900
- Seat of the design offices of François Hennebique

Photo: Georges Pilot

This emblematic building is the very first built entirely with columns, beams and slabs in reinforced concrete, still in excellent condition. It was constructed in order to house the design offices of François Hennebique at time of the Paris Universal International Exhibition (1900). The work of François Hennebique (1845-1921), a self-made man, was a main precursor for the construction of reinforced concrete structures: for example the Camille de Hogues Bridge in Chatellerault (1901), the first bridge in France, also the Roya Bridge (1908) and the Royal Liver Building in Liverpool, the highest skyscraper in Europe at the time (1910).

France

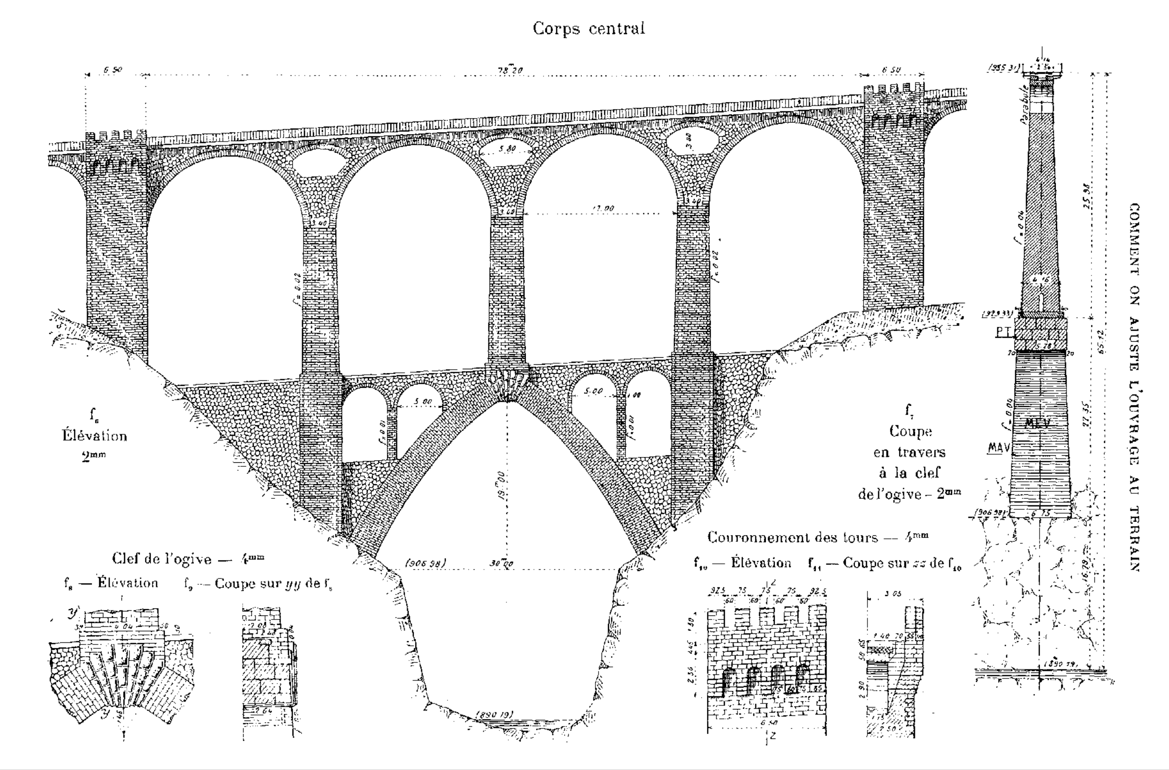
Photo: Lionel Maraval

BRIDGES

- **Fontpédrouse Viaduct**
- Fontpédrouse, Pyrénées Orientales
- 1908
- Historical monument
- Designed by Paul Séjourné
- Made of granite blocks

Fontpédrouse Viaduct (also called the Séjourné Bridge) is part of the Villeneuve-de-Conflent / Latour-de-Carol railroad, also known as Le Train Jaune (Yellow Train), in the Pyrénées Orientales. This line comprises many civil engineering works, especially two outstanding bridges: the Fontpédrouse Viaduct and the Gisclard Bridge, a precursor of cable-stayed bridges. It is a stone arch viaduct comprising two decks, 237 m long, with a main span 30 m long. Fontpédrouse Viaduct is registered as a historical monument. This bridge was designed by Paul Séjourné (1851-1939), an engineer from the Ecole Nationale des Ponts et Chaussées, who developed his career in the field of railroads. Paul Séjourné was the last and most distinguished engineer in so far as stone bridges are concerned. He developed the concept of light vaults built on main arches (Antoinette Bridge, 1884).

From the book *Paul Séjourné: Grandes Voûtes*, Tome V. (1913-1916)



France

Photo: Georges Pilot

BRIDGES

- **Luzancy Bridge** (Pont de Luzancy)
- Luzancy, Seine et Marne
- 1946
- Designed by Eugène Freyssinet, inventor of pre-stressed concrete

Luzancy Bridge was built over the Marne River. It is an early example of a pre-stressed concrete bridge, the first in the world of this dimension, 76 m long. Concrete segments were constructed close to the bridge, assembled in order to form beams, and then the beams were pre-stressed with cables, finally connected to previously installed cantilever beams. Four other similar bridges were built in 1949-1950, also on the Marne River.

Luzancy Bridge was designed and supervised by Eugène Freyssinet, inventor of pre-stressed concrete (in 1933, he was a consultant for construction of the Hesseler Weg Bridge in Germany, 33 m long). The work of Eugène Freyssinet (1879-1962), an engineer from the Ecole Nationale des Ponts et Chaussées, was well-known as a precursor of reinforced concrete bridges (His license dates from 1928). He was also involved in the design and construction of early concrete long bridges, for example the Boutiron Bridge (1912) and the Albert Louppe Bridge (1930). He applied pre-stressed concrete technology extensively to many kinds of civil engineering works: long bridges, dams, airship hangars, buildings, etc.

France

BUILDINGS

- **CNIT Exhibition Hall**
- Paris, La Défense
- 1958
- Largest concrete shell in the world

Photo: Georges Pilot

The Centre des Nouvelles Industries et Technologies (CNIT) is a masterpiece of the La Défense business area, located just outside Paris. The CNIT concrete triangular vault is the highest self-supported vault in the world (around 50 m high), also the largest concrete shell, offering a 22,500 m^2 surface without any intermediate supports. The length of the façades is 218 m. The bearing points of the vaults are connected with high-strength steel cables. The designer of the structure was Nicolas Esquillan, an engineer from the Ecole Nationale des Arts et Métiers in Chalons sur Marne. Esquillan (1902-1989) was involved in the design of many bridges and structures, several of which were world record holders at the time of construction: The La Coudrette bow string concrete bridge, 111 m long (1942); aircraft hangars at Marseille-Marignane airport, 102 m span (1951); and the La Voulte pre-stressed concrete rail bridge, 300 m long (1955).

Photo: Courtesy of Freyssinet

France

BUILDINGS

- **La Grande Arche**
- Paris, La Défense
- 1989
- High-performance concrete

Photo: Gorazd Humar

This tremendous building was constructed in the La Défense business area, in the outskirts of Paris, at the west end of the famous axis starting at the Louvre Museum, crossing the Obélisque, the Place de la Concorde and the Arc de Triomphe. La Grande Arche is a wide hollow cube, 112 m high, 112 m long and 106.9 m wide, covered with white marble plates. Its construction was a high-level technical performance. The building was constructed in high-performance concrete (125,000 tons): the roof (30,000 tons) is supported by four huge cast in situ beams 70 m long and 9.5 m deep. Civil engineering studies for the building were carried out by the Coyne et Bellier Office.

Photo: Courtesy of Freyssinet

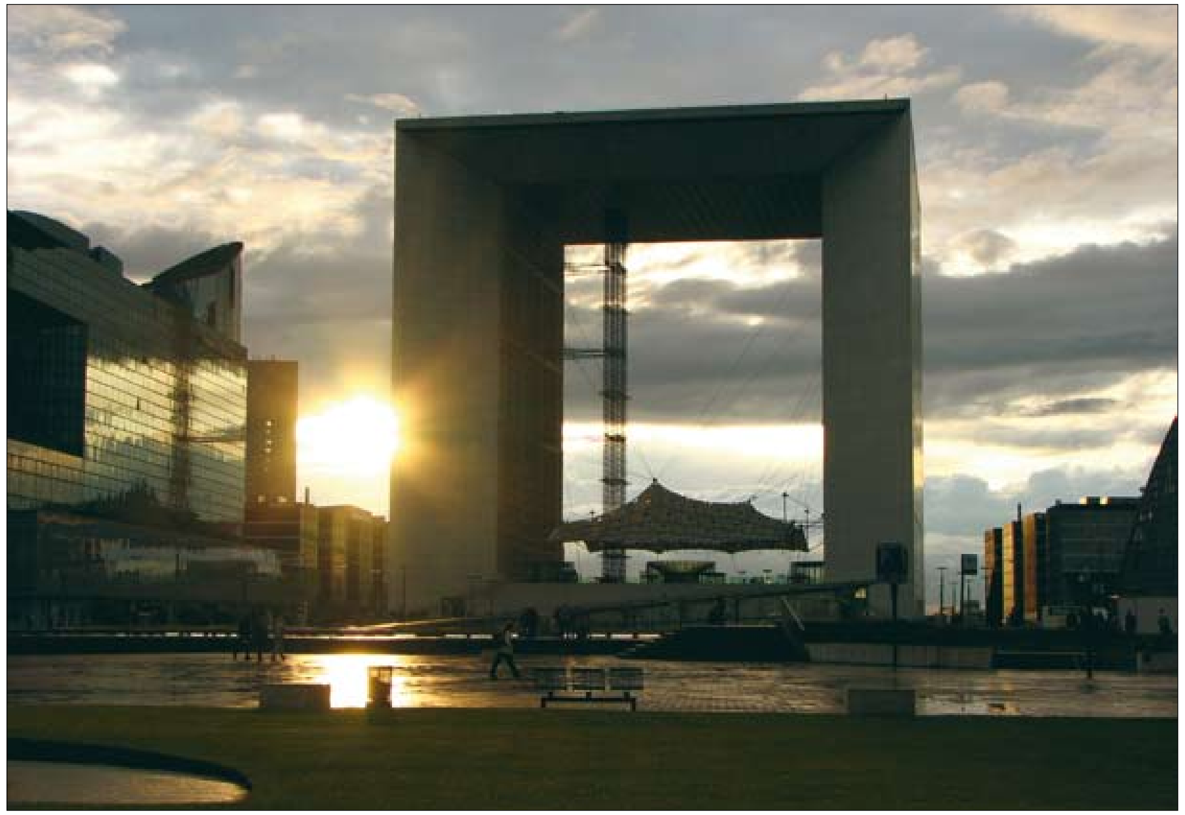


Photo: Gorazd Humar

France

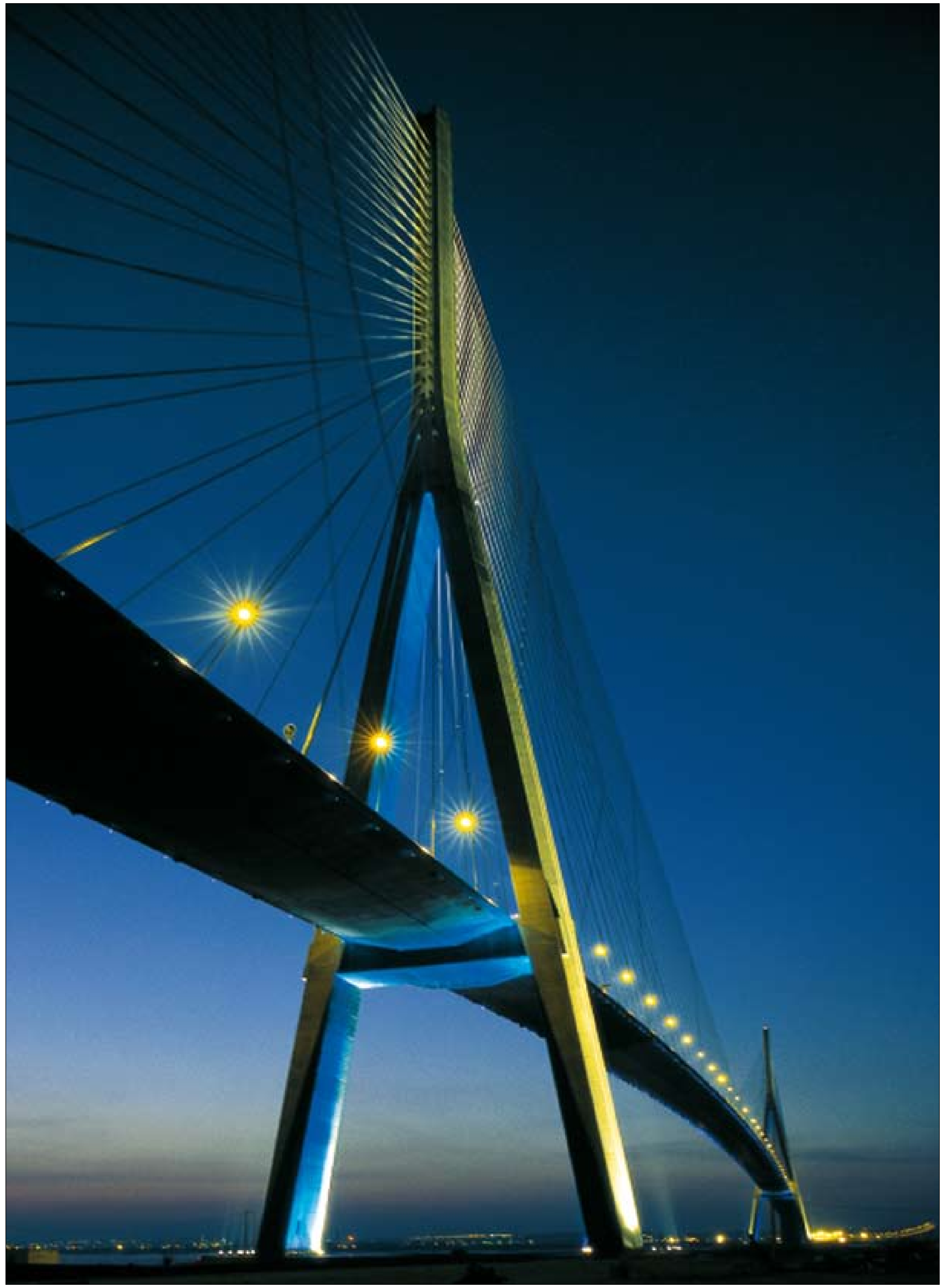
All photos: Courtesy of Freyssinet

BRIDGES

- **Normandie Bridge** (Le Pont de Normandie)
- Le Havre, Seine-Maritime
- 1995
- Main span 856 m, the longest cable-stayed bridge in the world at the time
- Main engineers: Michel Virlogeux and Bertrand Deroubaix
- Freyssinet stay cables

This road bridge, a cable-stayed bridge, is located in Normandy, part of Motorway A14, built on the estuary of the Seine River between the cities of Le Havre and Honfleur. It is a masterpiece of a new French motorway, in the west of France, linking northern and southern countries while avoiding Paris. A new bridge was necessary because traffic on other bridges (Tancarville Bridge and Brotonne Bridge) on the Seine River had become saturated. The Normandie Bridge is 2,141.25 m long, comprising the 856 m central span and two access viaducts, 737.5 m and 547.75 m long. The width of the bridge is 23.6 m, allowing four car traffic lanes, two cycle paths and two pedestrian lanes. The central span is supported by two towers, 214 m high, which receive the 184 stay cables attached laterally to the deck. The towers are founded on deep piles in bedrock, 50 m deep. The deck of the central span (856 m long) comprises two cantilever beams, constructed with cast in situ pre-stressed concrete segments nearby the towers, then connected to the main section of the deck, in steel, 624 m long. The deck is a box girder, laterally attached to the cables, designed to develop high rigidity and able to resist torsional forces.

At time of construction, Normandie Bridge was the longest cable-stayed bridge in the world. Engineers mainly engaged in the project were Michel Virlogeux (design) and Bertrand Deroubaix (construction). Both are engineers from the Ecole Nationale des Ponts et Chaussées. Michel Virlogeux, born in 1946, has been involved in a considerable number of bridge projects, as consultant or designer, including, for example, the Île de Ré Bridge and the Millau Viaduct.



France

All photos: Courtesy of Freyssinet

BRIDGES

- **Millau Viaduct** (Le Viaduc de Millau)
- Millau, southern France
- 2004
- Highest bridge construction in the world
- Design engineer: Michel Virlogeux
- Architect: Sir Norman Foster
- Contractors: Eiffage TP, Eiffel

Millau Viaduct is part of Motorway A75 (La Méridienne) linking Paris and Clermont-Ferrand to Pezenas, later on Béziers, in the south of France. It is built over the valley of the Tarn River, near the town of Millau. The bridge represents a considerable improvement in road transport, because the Millau bottle neck of car traffic is now ameliorated. The owner of the viaduct is Compagnie Eiffage du Viaduc de Millau and the engineering company was SETEC. This outstanding viaduct is 2,460 m long, comprising 8 cable-stayed spans, the longest being 342 m long, with a 32 m width for two 2x2 road traffic lanes. It is the longest cable-stayed bridge in the world. The steel deck is composed of elements manufactured in a factory, assembled and welded in situ. The profile of the deck is designed taking into account aerodynamic resistance against strong winds. The deck bears on piers of exceptional height, the highest being 245 m, constructed using high-performance concrete. The shape was especially developed in order to enhance the elegance of the viaduct. Piers are supported by foundations comprising 4 concrete piles, 5 m in diameter, around 15 m in depth. The deck is supported by axial fan stays linked to steel pylons, 87 m high, placed in continuity with the piers. The viaduct holds a world record for the height of the complex pier-pylon, around 343 m, more than Eiffel Tower. 1500 tons of Freyssinet stays were installed to hang the steel deck.

Millau Viaduct was built in 38 months. The design engineer was Michel Virlogeux and the architect Sir Norman Foster. Michel Virlogeux, born in 1946 and an engineer from the École Nationale des Ponts et Chaussées, has been involved in a considerable number of bridge projects, as consultant or designer, including, for example, the Île de Ré Bridge and Normandie Bridge.

Millau Viaduct

Great Britain

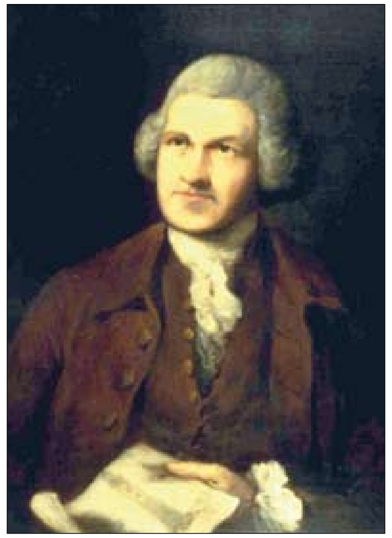
Introduction

John Trew (fl. 1564–1588)

Great Britain has a world famous civil engineering heritage, epitomised by the iconic sites of the Tower Bridge (London), and Forth Railway Bridge (Scotland), which feature on so many tourists' photographs and postcard views.

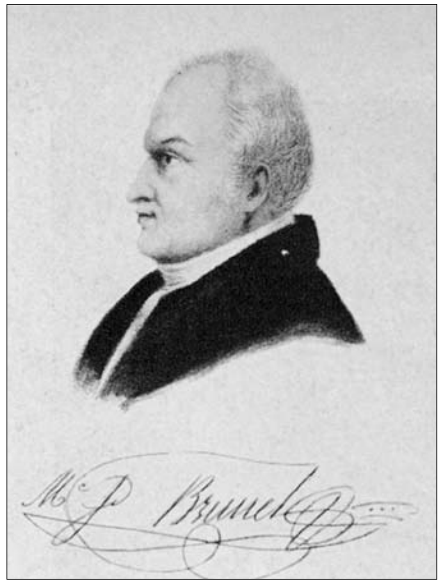
Whilst the profession can be characterised as a child of the Industrial Revolution, with the term 'civil engineer' first being employed c.1760, and the Institution of Civil Engineers, the world's first professional engineering body, being established in 1818, evidence of 'civil engineering' can be found in the British landscape dating back centuries before then. Many of the better known earlier works are clearly foreign – most obviously Roman roads, and water supply schemes such as that at Dorchester. Mediaeval works such as a weir over the Dee at Chester, and the canalised approach to Rhuddlan Castle (Wales) were associated with military engineers employed by the Norman–French monarchy which ruled much of the British Isles for over 400 years. 'Dutch' engineers were also employed in land drainage works from medieval times, culminating in the activity of Cornelius Vermuyden in the first half of the seventeenth century. However, this must be set against the largely anonymous tradition of bridge builders and millwrights who helped shape the mediaeval landscape and must have featured indigenous talent.

From the Tudor period evidence of such individuals as John Trew, on the Exeter Canal, Lea Navigation and Dover Harbour marks the beginning of a proto-civil engineering profession. In the military sphere great dockyard systems were being developed at Portsmouth and elsewhere. Although learning from foreign examples, land drainage and river navigations were increasingly carried out by British 'engineers', and the last major work to be led by a foreign born engineer was Charles Labelye's Westminster Bridge (1738–1750). This, the first major crossing of the Thames in London for 600 years, was eclipsed in both aesthetic terms and engineering qualities within twenty years by Robert Mylne's Blackfriars Bridge (1760–1769). By then John Smeaton's Eddystone lighthouse had been completed and the heroic period of British civil engineering had begun, captured by Samuel Smiles in his *Lives of the Engineers* and featuring the stellar talents of Smeaton, James Brindley, John Rennie, Thomas Telford and George and Robert Stephenson. Their achievements are represented here. Telford's Pontcysyllte Aqueduct, is a fitting climax to the canal age introduced by Brindley, and, with Iron Bridge, heralds the Age of Iron, the use of which transformed structural design.


John Smeaton (1724 - 1792)


Thomas Telford (1757 - 1834)


William Lindley (1808 - 1900)



Marc Isambard Brunel (1769-1849)

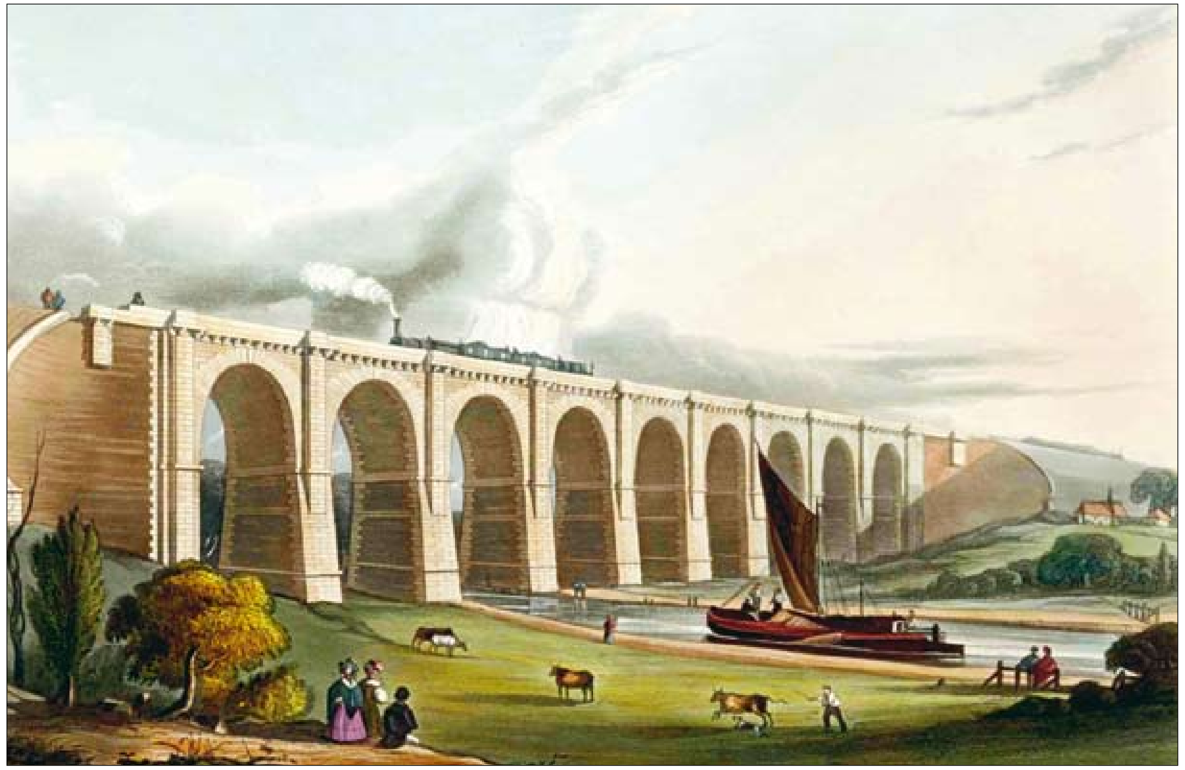
The pioneering use of steam locomotion in Britain culminated in the Liverpool and Manchester Railway, which opened the Railway Age and unleashed the diaspora of British civil engineering talent across the globe. Much of this development was funded by Britain's success as a trading nation. Small eighteenth century harbours were rapidly supplanted by the great dock systems of London, Liverpool and Hull.

The contributions and ingenuity of British civil engineers led the world through the nineteenth century, with a succession of record-breaking bridges beginning with Telford's Menai Suspension Bridge and culminating in Fowler and Baker's Forth Railway Bridge.

Public health engineers tackled problems of water supply and sewage disposal with increasing effectiveness from the middle of the nineteenth century. Their work, often featuring major dams, impacted on both towns and the countryside. Its influence, as with the railways was felt not only in Britain, but also in continental Europe – the work of the Lindley family being particularly evident in towns like Hamburg and Warsaw. There were, of course, more direct influences in the countries of the British Empire.

Twentieth century works may be less iconic, but in Liverpool's Liver Building, and London's Post Office Tower, they provide landmark structures. Telecommunications have come to dominate the twenty-first century, and the Museum Tower was built on the cusp of that development. Motorised road transport dominated the second half of the twentieth century, and provided spectacular opportunities for civil engineers to dominate the landscape once more.

Liverpool & Manchester Railway, Sankey Valley Viaduct, 1830



Great Britain

HARBOURS

- **HM Dockyard, Portsmouth**
- No. 1 Basin and Dock Group
  No. 5 Dock and No. 6 Boathouse
- 17th - 18th century
- The Historic Dockyard

The oldest part of Portsmouth Dockyard is the south-west sector adjacent to the main gate on The Hard. It centres on No.1 (non tidal) Basin with Nos.5, 4, 3 and 2 Docks. Activities started in 1212, with major development in 1496 and 1658, but, being timber, the quays and docks have been replaced by No.1 Basin and No.5 Dock, the first masonry structures. These were built by Templar and Parlby, between 1692 and 1698 to the design of Edmund Dummer, Surveyor to the Navy Board. Purbeck stone faced with Portland was used and all dock and quay walls and timber dock floors were founded on a grillage of timber piles.

In 1764 the basin width was increased. The basin entrance was modified and deepened by 2ft. In 1772 No.4 Dock was built, replacing a slipway, and in 1777 a reservoir was formed to the north for draining down Nos.5 and 4 Docks.

In 1796 the new Director General of Naval Works, Brigadier Sir Samuel Bentham, started to enlarge No.1 Basin southwards with a new entrance and two docks, Nos.3 and 2. The new entrance had an inverted elliptical arch floor, a design used at Ringsend docks, Dublin, in 1791 by William Jessop. No.3 Dock, the last in the group, was given an inverted masonry arch floor. The timber floors of the other docks have subsequently been replaced.

The Navy's need for pulley blocks was enormous, so Bentham persuaded the Navy Board to install mass production block making machinery, designed by Sir Marc Brunel, in a building erected over the reservoir referred to above. The machinery was made by Henry Maudslay and started production in 1808.

Since 1922, No.2 Dock has housed Nelson's flagship of the Napoleonic Wars, HMS *Victory*. A permanent concrete cofferdam replaced the old gates. The Tudor *Mary Rose* lies in No.3 Dock. Both ships are open to the public and were joined in 1987 by *Warrior* the British Navy's first ironclad warship, moored alongside a new jetty, with access just inside the dockyard main gate.

Close to the dock is No.6 Boathouse, which is a fine yellow brick industrial building with stone dressings. It is 164ft long, 120ft wide, with floor to floor heights of 19ft 4in, 16ft and 10ft 3in to roof truss ties. Engineering interest centres in the grid of columns and beams of 1845 to enable the upper floors to be strong enough to accept boats.

Cast iron Tuscan columns of 1ft 6in diameter at base set on a 40ft by 10ft grid, support cast iron I beams with a clear span of 38ft 9in. The beams are 2ft 9in deep with 13in wide bottom flanges, 5in top flanges and 2in thick webs. Cast in the web are the words 'Load on this girder should not exceed 40 tons'. This corresponds to a floor loading of about 200lbf/ft^2. The beams have a wrought iron tie system consisting of two 4 ½ in by 2in wrought iron flats under the bottom flange, tensioned by taper keys to relieve the beam of tension. Elaborate pinned supporting points are provided at the 1/3 span positions to minimise friction during tensioning. The secondary beams are also cast iron, 10ft 9in span, with arched supports. The boathouse now houses a number of activities generally aimed at younger visitors to the Historic Dockyard.

Great Britain

BRIDGES

- **Pont Cysyllte Aqueduct**
- Dee Valley, Llangollen
- 1795 - 1805
- Built by Thomas Telford
- World Heritage Site

Described by Sir Walter Scott as 'the greatest work of art he had ever seen' this cast iron canal aqueduct, 1,027ft long, carries the Shropshire Union Canal over the valley of the Dee. Now nominated as a World heritage site it compares with similar iconic works like the Pont du Gard in terms of its visual impact in the landscape. Designed by Thomas Telford (1757-1834) its ironwork was cast by William Hazledine.

Thomas Telford was appointed in September 1793 by the Board of Ellesmere Canal Company as its Agent to work under the direction of William Jessop its chief engineer on the Ellesmere Port to Chirk Canal. This canal was to create an outlet for coal and lime to the Mersey. By far the greatest physical problem was the crossing of the Dee Valley east of Llangollen. Plans were first drawn in 1794, but it was not until a year later in 1795 that the innovation of a cast iron trough supported on masonry piers was put up by Telford and accepted as the most economic method of carrying the canal at a height of 125ft above the level of the Dee, and with a total length 1,027ft, thus eliminating two very costly sets of locks. This very novel plan was accepted on account of the success of Telford' s smaller cast iron aqueduct at Longdon-upon-Tern on the Shrewsbury Canal, which was completed in 1795.

The length of the supported waterway is 1,007ft carried on 18 rectangular masonry piers giving a clear span between piers of 45ft. The piers are hollow above 70ft, but strengthened with cross walls the outer walls being no less than two feet thick.

At the top, piers are 7ft wide x 11ft deep. The south embankment reached a height of 93ft, the greatest earthwork in Britain at that time. The width of the cast iron trough is 11ft x 5ft deep to allow an easy passage for a 7ft wide laden barge. The tow path 2ft wide is cantilevered over the water on the East side. There is a hand rail only on the towpath side. Thus even now to cross this aqueduct is a daunting experience. The channel consists of a cast iron plated trough supported on 4 cast iron arch ribs spanning between masonry piers. The towpath is cantilevered over the canal with cast iron supports and is protected with a handrail. The off-side of the canal trough has no such protection. For anybody walking or boating across, the exposure is vertiginous.

Telford made up his construction team with his old friend from Scotland, Matthew Davidson, as inspector of works, John Simpson, straight from Montford Bridge as chief mason assisted by John Wilson of Dalston, Cumberland. William Hazeldine won the contract to supply the iron troughs from his foundry at Plas Kynaston only half a mile distant, and connected to the aqueduct site by a tramway. The foundation stone was laid on 25 July 1795, but due to many problems, and a slump in trade, it was not opened until November 1805. The total cost was £47,018. Throughout, Telford was responsible for design and construction, but under the overall responsibility of Jessop.

The ceremonial opening took place on 26 November 1805 to the firing of a cannon by the Shropshire Volunteers. Six boats crossed and returned, the first two boats carrying the Directors and Staff of the Canal Company, the next two carried the band of the Shropshire Volunteers who played continuously, and the last two were empty going over but returned filled with coal. In the words of the opening ovation on the 26 November 1805 – 'Mr Telford, with the advice and judgement of our eminent and much respected engineer Mr Jessop, invented and unabated diligence carried the whole into execution'. The aqueduct has survived for two centuries with only minor repairs

Pont Cysyllte Aqueduct

Great Britain

BRIDGES

- **The Iron Bridge over the Severn**
- Coalbrookdale, Shropshire
- 1776 - 1781
- The first cast iron bridge
- World Heritage Site

The upper Severn gorge became one of the birthplaces of modern industry when in 1709 Abraham Darby, originally a Bristol brass founder, began to smelt local iron ore with coke made from local coal at Coalbrookdale. To enhance the communications of the area, a bridge over the River Severn was proposed between Broseley and Madeley Wood. Severe floods in earlier years suggested a single span to avoid piers in the river. In February 1776, a Bill was laid before Parliament for the construction of a bridge in cast iron. Thus was born the Iron Bridge, the first major bridge in the world to be constructed wholly of cast iron, and which gave its name, Ironbridge, to the settlement which sprang up around it.

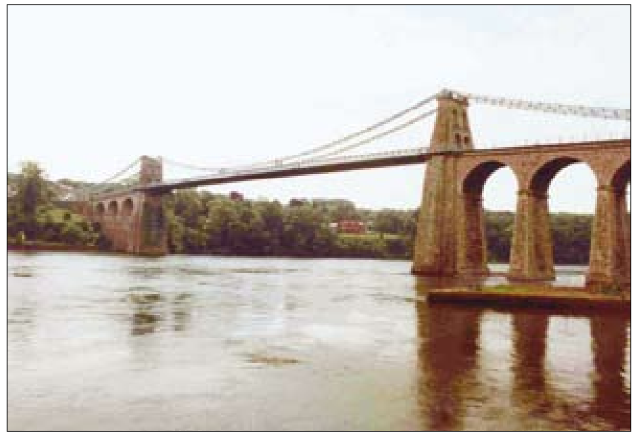
Photo: Robert Cortright, USA

The bridge clears the river in a single arch of 100ft span and is made up from ten half ribs, each cast in one piece by Abraham Darby III in his Coalbrookdale furnace. The project in essence is credited to the architect Thomas F Pritchard.

Construction of the bridge took one and a half years and it was opened on New Year's Day 1781. It contains just over 378 tons of ironwork, probably equivalent to three or four months output from a contemporary furnace. It survived flood and tempest to carry vehicular traffic until 1931 when it was closed to all but pedestrians. Major repairs were necessary at intervals during the life of the bridge, being occasioned mainly by the tendency of the sides of the gorge to move towards the river.

This bridge and its toll-house on the south side are now preserved as a World Heritage Site and as a monument to the pioneering spirit of British engineers and craftsmen.

Great Britain



BRIDGES

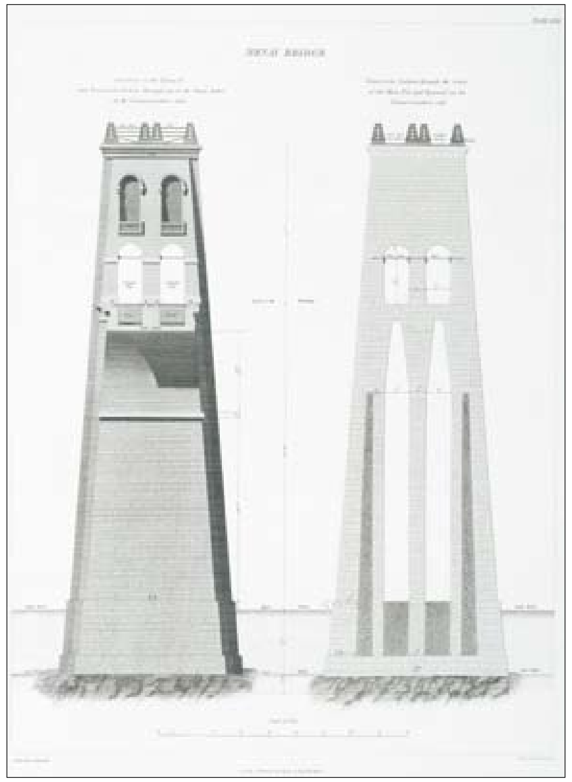
- **Menai Bridge**
- Menai Strait, Wales
- 1819 - 1826
- Telford's finest work
- Main span 579 ft (177 m)
- It was the longest span in the world at the time

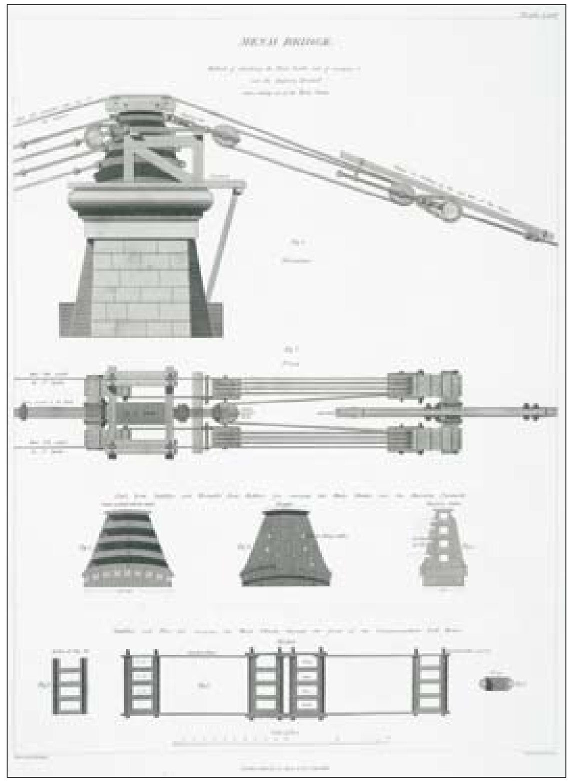
Suspension bridges, although widely used in mountainous areas like the Himalayas for centuries, only assumed their modern, level deck, form in the early nineteenth century. Although many early examples were modest affairs, Thomas Telford realised this form of bridge was suitable for very long spans. He carried out extensive tests for a proposed bridge across the Mersey of over 300 metres before being approached about the Menai Crossing. In 1817 the Holyhead Road Commissioners instructed him to prepare plans for a bridge to replace the ferry across the Menai Strait. The plans, for what is generally regarded as Telford's finest work, were ready by February of the following year.

Photo: Robert Cortright, USA

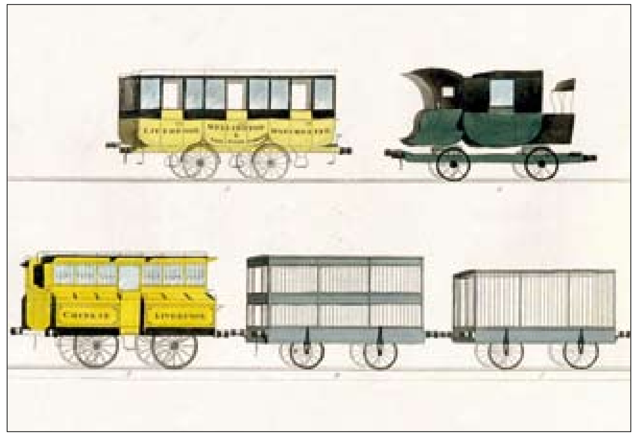
The construction took John Wilson, the contractor, a period of seven years from 1819. The bridge has an overall length of 1,000ft, seven stone approach spans of 52ft and a main central suspension span of 579ft, tower to tower, carrying the road 100ft above sea level. It was the longest span in the world and heralded the modern era in bridge construction.

The deck was suspended from four sets of wrought iron chains, the links for which were made by William Hazledine. Modifications to the bridge were made following damage by a storm in January 1839. In 1893 Sir Benjamin Baker replaced the timber deck by steel troughing on flat–bottomed rails. In 1940 the chains were replaced by two sets of steel chains; the deck was rebuilt in steel to take heavier road traffic and a cantilevered footway was added on each side, so giving the bridge the appearance that it has today. Nevertheless, the modern alterations do not detract from the gracefulness of Telford's original structure, set as it is in magnificent scenery.





Great Britain



RAILWAYS

- **Liverpool & Manchester Railway**
- Designed by George Stephenson
- 1830
- First passenger railway in the world

Opened on 15-16 September 1830, this ranks as the first main-line railway in the world and includes many major engineering works. Designed by George Stephenson, internationally regarded as the father of the Railway, it is generally remembered for the Rainhill trials in which the Robert Stephenson-designed Rocket locomotive demonstrated the viability of steam traction.

The eastern suburbs of Liverpool are on a sandstone plateau, and the first (1824) scheme for a railway from Liverpool Docks to Manchester was from Princess Dock, north of the town. Opposition from titled landowners caused the scheme to be rejected by Parliament; but in 1826 Parliament approved a route passing through the plateau in deep cutting and descending to near Queen Dock, south of the town, by a steeply inclined tunnel, 2111 yards long, the first railway tunnel in the world. This Wapping Tunnel was started early in 1827 from the ends and from intermediate shafts: the headings had met by mid June 1828 and it was completed by late 1828, despite a fall of a roof under Crown Street.

The railway as authorised in 1826 started at the Liverpool Dock Road, there named Wapping, and extended to Irwell Street, Salford. Various deviations were authorised by an act of 1828 and a further act of 1829 changed the Manchester terminus from Irwell Street to a site, within Manchester, east of Water Street and North of Liverpool Road. The length between termini was 31 miles. At the Liverpool end, though, the termini were complex in that a separate station was provided for passengers (and coal) at Crown Street, just outside the Liverpool boundary and some 30 feet above Wapping Tunnel: it was linked by a single-line tunnel, too small for locomotives, to a rectangle cutting in the rock, 150' x 90' x 408' deep, at the head of the Tunnel incline. This 'engine station', equipped with two winding engines for traction. Thence for five miles the line runs, with easy gradients, to the foot of the Whinston Incline, which rises at about 1 in 91 to the Rainhill Level, whence it descends by the Sutton Incline at a similar gradient. It was originally intended to use locomotives throughout, except in Wapping and Crown Street Tunnels. From the foot of the Sutton Incline to the Manchester terminus the gradients were easy.

The total cost of the railway was £820,000, about twice the original estimate for the easier route. Wapping Tunnel cost £45,000 and Sankey Viaduct, designed by Jesse Hartley, £46,000. Sixty three other bridges were built for £100,000, including the Cheese Bridge at Rainhill The 4 and three quarter mile crossing of Chat Moss, once thought impossible, was achieved for £28,000 by side ditching and laying it with stone, clay, etc and the use of fascines. Other major works included the spectacular cutting through Olive Mount, Liverpool, with almost vertical sandstone sides up to 70ft high, and the 66ft span stone arch over the River Irwell near the Manchester terminus. The total quantity of excavation for the railway was about 3m. cubic yards.

The Crown Street terminus proving inconvenient, the L & M R Company constructed an extension towards the city centre. Authorised in 1832 and opened 15 August 1836, from Edge Hill to Lime Street passenger station. It was in tunnel from Tunnel Road to only 250 ft short of the eastern side of Lime Street, on a gradient of about 1 in 90, which was at first deemed to need rope haulage. Their tunnel's contractor, William Mackenzie, went on to build many early railways in France, with Thomas Brassey as his partner. At the Manchester end a branch was opened in 1844 from Ordsall Lane to a new one – platform station, Victoria, shared with the Manchester and Leeds Company.

The L & M R was originally laid with 35lb/yard T-shaped malleable iron rails supported every 3 ft by 4 cu ft stone sleepers where the formation was firm and by oak sleepers on the 13 miles of embankments. Later in the nineteenth century the line was quadrupled west of Huyton Quarry and east of Barton Moss Junction, but only from Lime Street to Edge Hill is quadruple now. Kenyon Junction has also been removed.

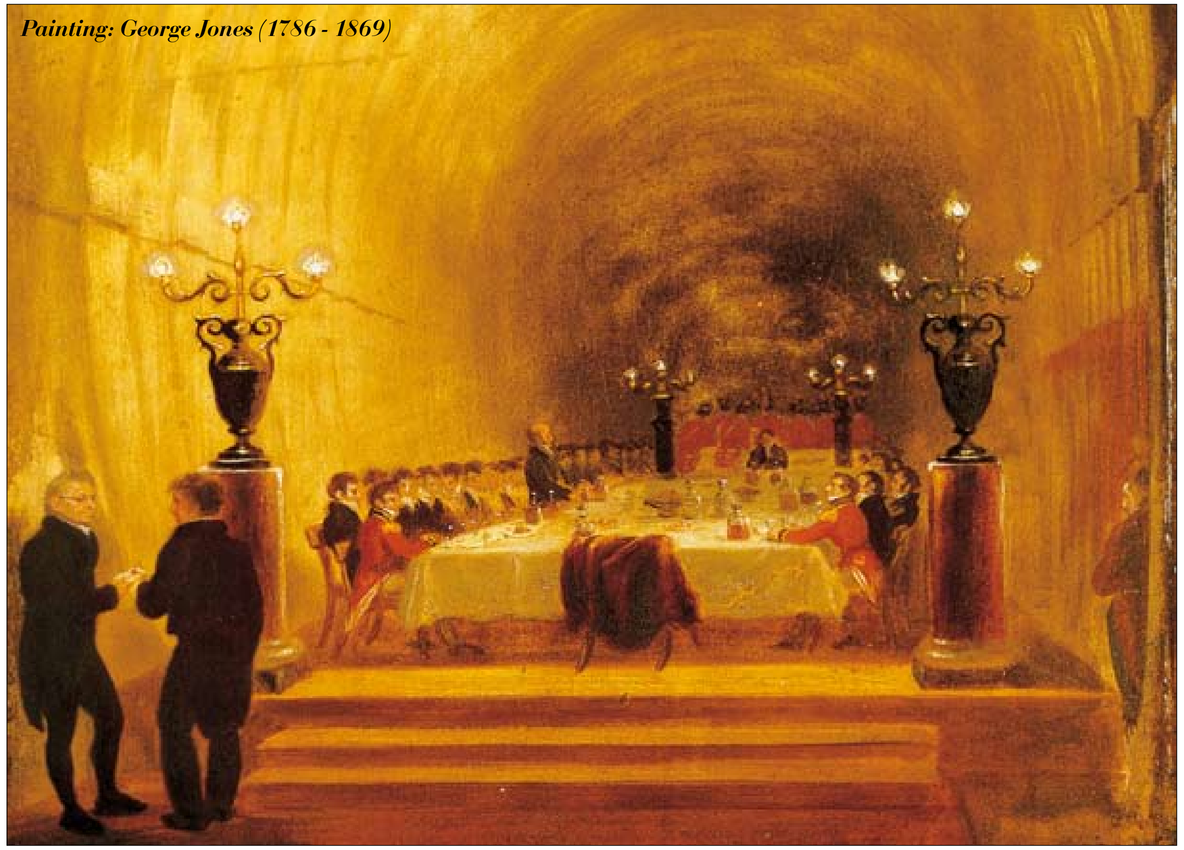
The Lime Street Terminal has been rebuilt 3 times, and has an interesting crescent truss roof, but the original Manchester terminus survives largely intact as part of Mnachester's Museum of Science and Industry. A few interesting station intermediate buildings survive from the early years, such as Edge Hill and Earlestown.

Great Britain

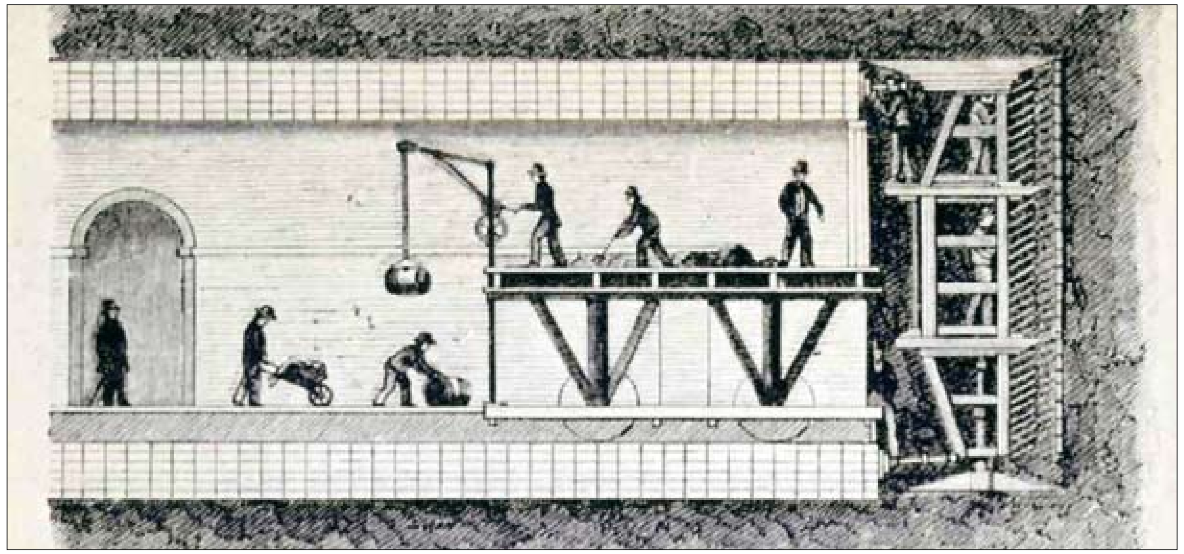
TUNNELS

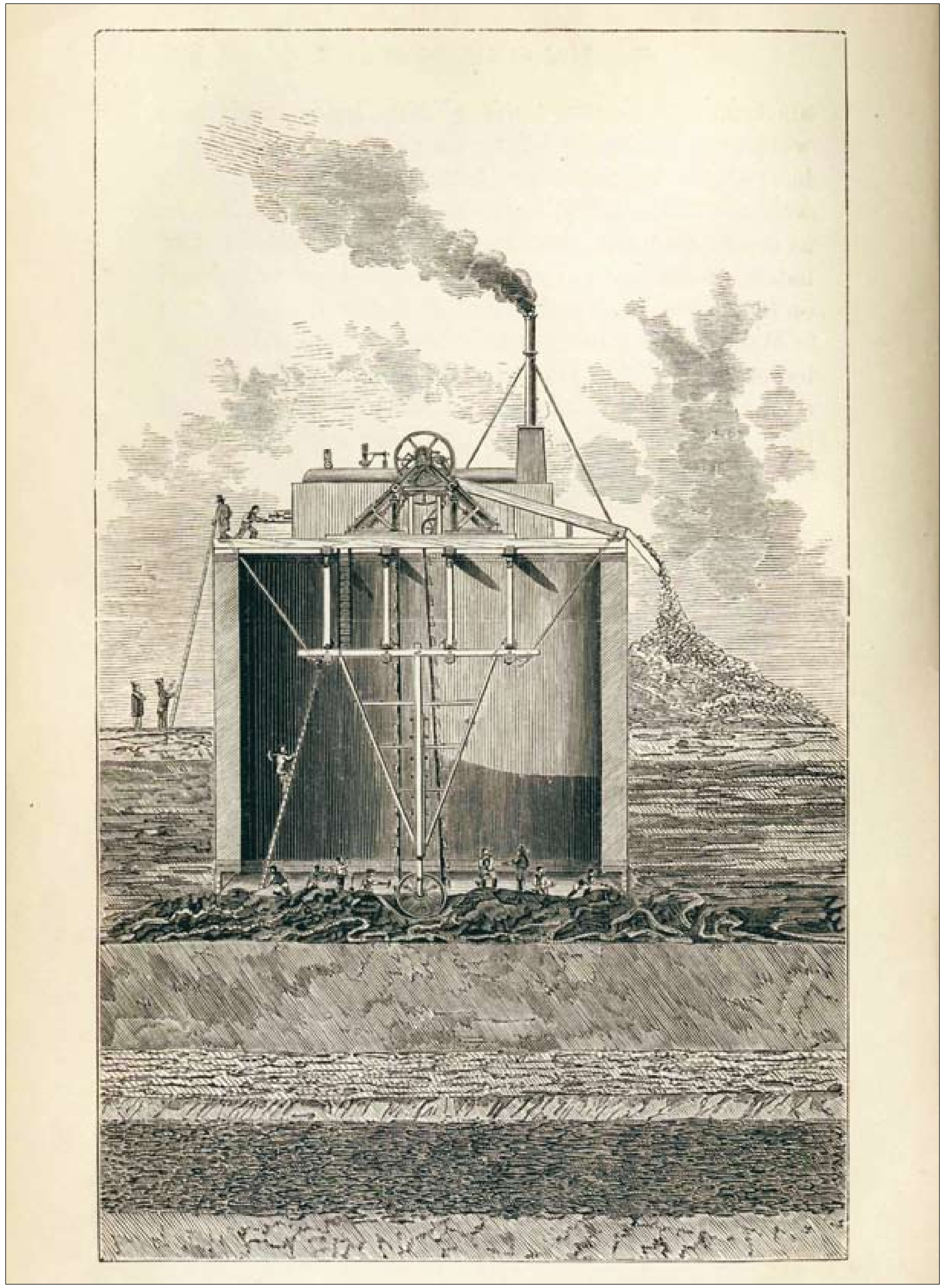
- **The Thames Tunnel, London**
- Rotherhithe- Wapping
- 1825 - 1843
- Marc and I. K. Brunel
- The first subaqueous tunnel
- Length of the tunnel 1200ft (366 m)

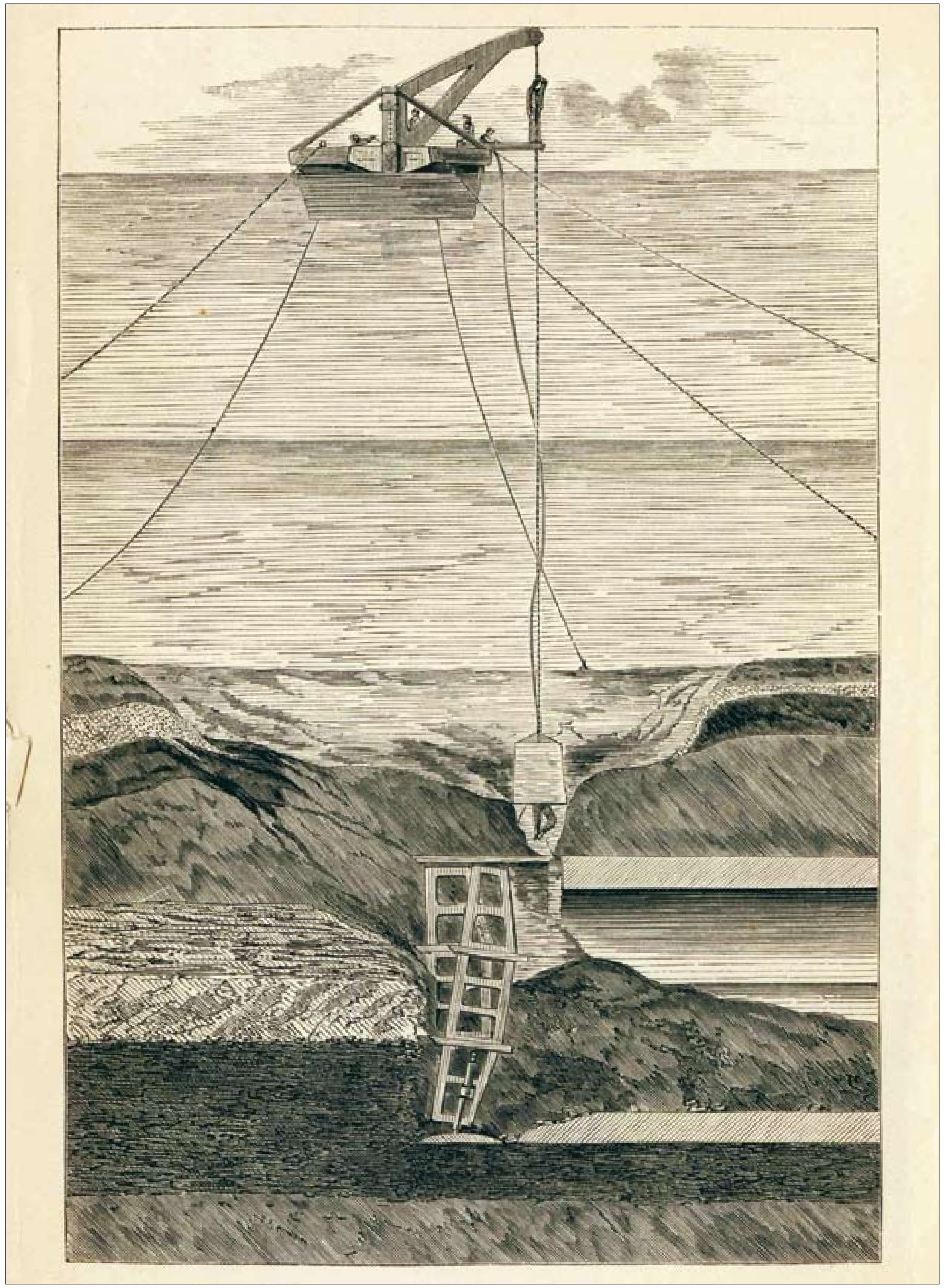
The prototype for all modern soft ground and subaqueous tunnel, the Thames Tunnel is undeniably the most important example of civil engineering heritage in London. In 1823 (Sir) Marc Brunel produced a plan for a tunnel beneath the Thames from Rotherhithe to Wapping, in the heart of the Port of London. A bridge crossing was impractical because of the spans and interference with river navigation. Work began in February 1825 with the setting out of the Rotherhithe shaft. The 50ft diameter, 40ft high brick shaft was built above ground and then sunk into its final position. The rectangular tunnelling shield, built by Maudslay in Lambeth, was then assembled at the bottom of the shaft facing the river and the heading towards Wapping began in November 1825. The two archways in the tunnel are contained within a rectangular mass of brickwork 37ft 6in wide and 22ft 3in deep. In May 1827 the first irruption of the river into the workings occurred when the tunnel was 549ft long. The second irruption, in January 1828, was more severe – six men died, Marc's son, the young I K Brunel was severely injured, the shield was damaged and work ceased. There were financial problems, and in August the tunnel was walled up. In 1833 a loan from the Treasury enabled work to re-start. The old shield had to be removed and a new version, built at Rennies' Albion Ironworks, was installed and started moving in February 1836. After two more irruptions of the river Brunel took possession of the Wapping shaft site in June 1840. On 25 March 1843 the 1,200ft tunnel was opened to pedestrians, and spiral staircases in the shafts provided access. Although planned for, the tunnel was never used, for vehicular traffic. In May 1865 the East London Railway Company was formed to make use of the tunnel to link railway systems north and south of the Thames. The first train ran through the tunnel on 7 December 1869. The line was electrified, and on 31 March 1913 the Metropolitan Railway began a service over the East London Line. The line became part of London Underground on 29 January 1914, and remains part of the system today. On 24 March 1995 the whole tunnel was Listed Grade II*, the whole line is being refurbished as a major link in the London Transport System.

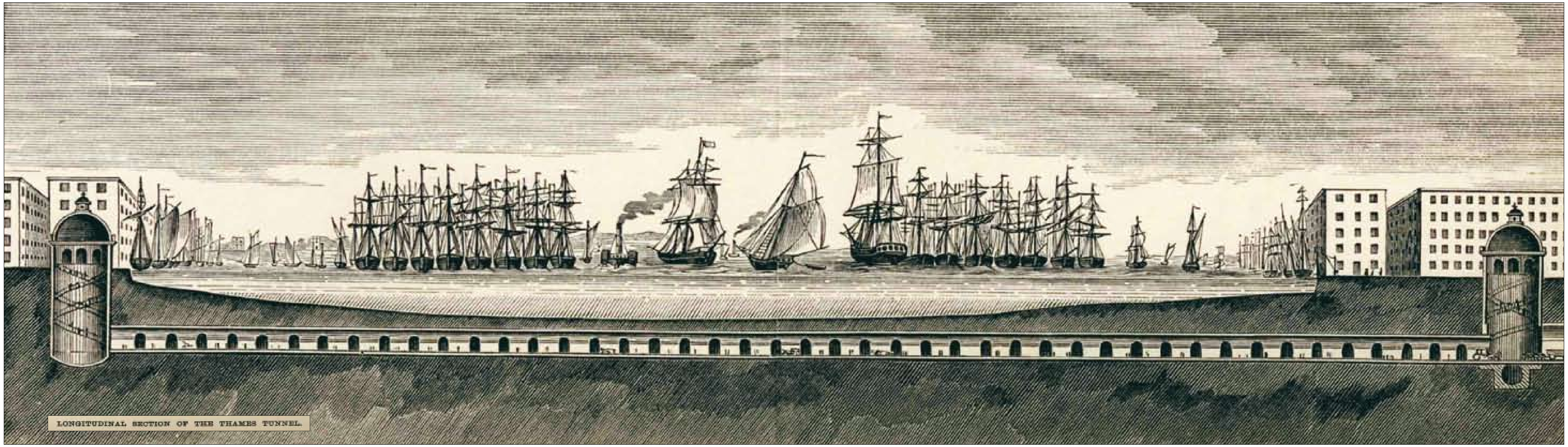


Painting: George Jones (1786 - 1869)

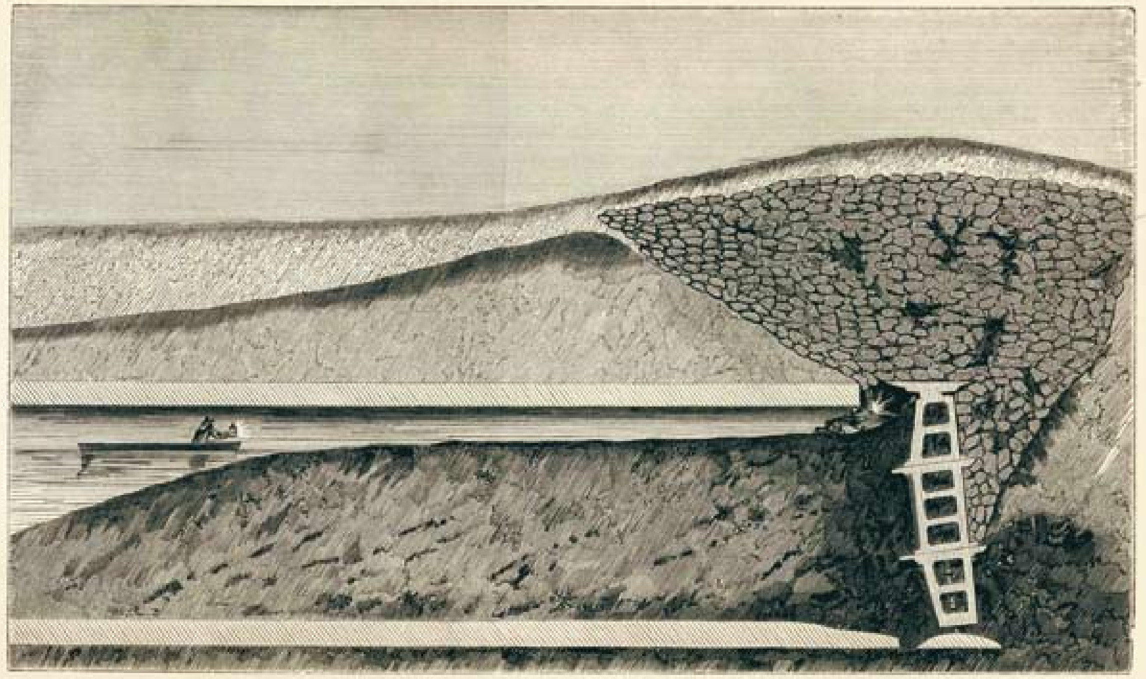




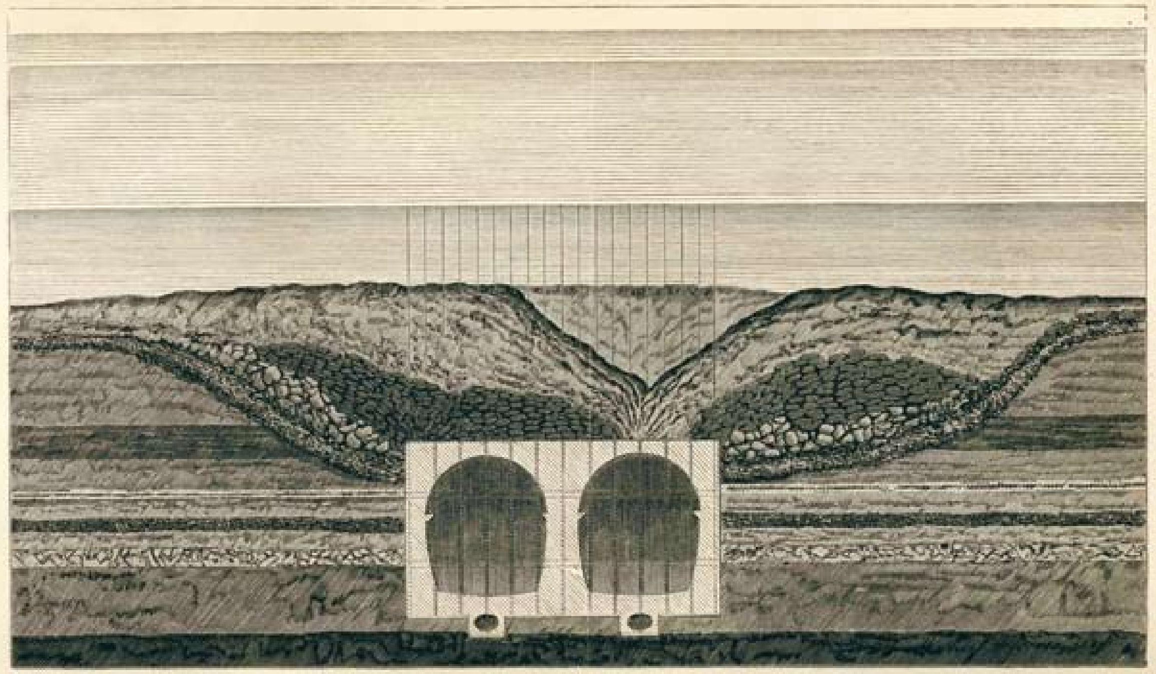




LONGITUDINAL SECTION OF THE THAMES TUNNEL.



FIRST VISIT TO THE SHIELD AFTER THE FIRST IRRUPTION OF THE RIVER.



CROSS SECTION OF TUNNEL AND LONGITUDINAL SECTION OF RIVER, SHOWING THE EXTENT OF CAVITY FORMED BY THE IRRUPTION.

Great Britain

BUILDINGS

- **Salt's Mill, Saltaire**
- Designed by William Fairbairn
- 1853
- World Heritage site

Multi-storyed textile mills were an important part of the British industrial landscape. Early examples were water powered, but from the early nineteenth century steam powered mills dominated. Designed by William Fairbairn, millwright and ironwork contractor, for Titus Salt this was one of the earlier of the largest textile mills to incorporate modern features of fireproof construction, gas lighting, air conditioning winter with powered machinery of the latest type. Opened in 1853, it included a room 550 ft long in the main building, thought to be the largest room in Europe. Today the mill houses a cultural centre.

An estate of nearly 900 houses for the employees, with schools, shops and church, was part of the project, and now the whole forms a World Heritage site.

Great Britain

BUILDINGS

- **Kirkaldy Testing Works**
- Southwark Street, London, SE1
- 1874
- Today Museum

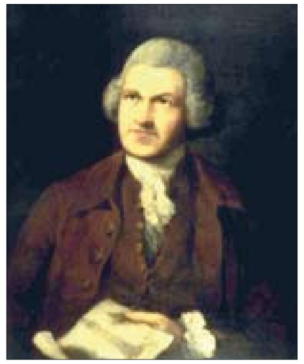
David Kirkaldy (1820–1897) established his independent firm for testing engineering materials in London, which served the construction and other industries from 1866 to 1965. Kirkaldy designed the unique testing machine himself and had it built, at his own expense, by Greenwood & Batley of Leeds. It is a universal machine 47ft 6in long, and was designed to test in tension, compression, bending, torsion, shear, punching and bulging. The machine is capable of applying a load of 440 tons. The present purpose-built building at *99 Southwark Street* was opened in January 1874. After the Tay Bridge disaster of December 1879, pieces of the wrecked bridge girders were recovered from the bed of the river Tay and brought to the Kirkaldy Testing Works for testing in the spring of 1880.

Three generations of the family ran the firm until the younger David retired in April 1965. The works, under new management, finally closed in 1974. The testing machine remains in position and in working condition as the centrepiece of The Kirkaldy Testing Museum.

Great Britain

TOWERS

- **Eddystone Lighthouse**
- English Channel
- The present lighthouse was built in 1882
- John Smeaton built the third lighthouse (1756-1759)



John Smeaton (1724-1792)

Eddystone reef was a notorious threat to shipping in the English Channel and approaches to Plymouth for centuries, but its inhospitable location deterred the placement of a warning beacon for centuries. The present (1882) lighthouse, the 4th on the site, is a circular masonry tower on 44ft dia plinth 22ft high. The height of the light above MHW is 135 ft. and the light has a range of 17.8 miles, and is equipped with a catadioptic lens. The lighthouse was originally lit by paraffin lamps and electrified in 1959.

Alongside the existing lighthouse is the stump of the third and best known lighthouse, designed by John Smeaton and erected 1756-1759. The first two, Wynstanley's, in existence 1698-1703, and Rudyerd's 1708-1755, were largely timber structures, and both were destroyed in storms with loss of life. Smeaton's, in service 1759-1882, was a masonry tower, designed with much care. Its completion marked the entry of Smeaton into the civil engineering profession and a representation of the tower has been used in one form or another by the Institution of Civil Engineers on its literature for most of its existence. More accessible than Eddystone rocks, the top of Smeaton's tower can be seen on Plymouth Hoe.

Great Britain

DAMS

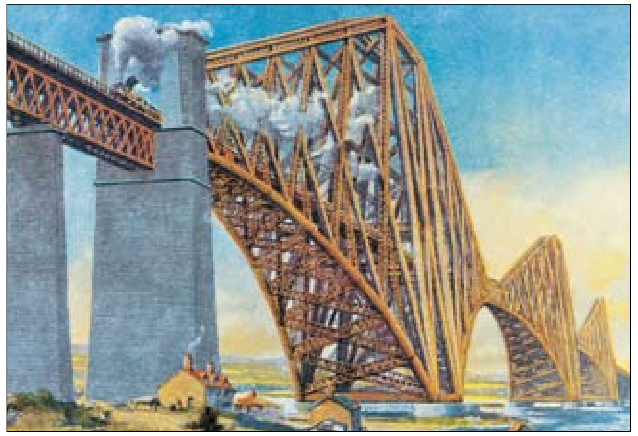
- **Caban Coch Dam**
- Elan Valley
- 1892 - 1904
- The Engineer: James Mansergh

In 1892 the Birmingham Corporation Water Act authorised the construction of reservoirs in the Elan and Claerwen valleys, south-west of Rhayader, and of an aqueduct to convey water to the city. James Mansergh was the engineer. The initial works in the Elan valley comprised three reservoirs which were built by direct labour and completed in 1904.

Caban Coch is the first dam up the valley from Rhayader. It is 610ft long, 122ft high and 5ft wide at the crest and is built of cyclopean mass concrete faced with block-in-course masonry. The downstream face has an inwardly curved batter, struck to a 340ft radius, to within 15ft of the top, from which point to the crest the curvature is reversed.

The area of the reservoir is 500 acres with an impounding capacity of 7,815 million gallons. A novel feature of the scheme was the submerged dam built across the reservoir at Garreg Ddu, about 1½ miles upstream from Caban Coch. At times when the reservoir is very low this keeps the water at the required level to feed the aqueduct, while the water impounded in the reservoir below it can be used to provide compensation water.

Great Britain



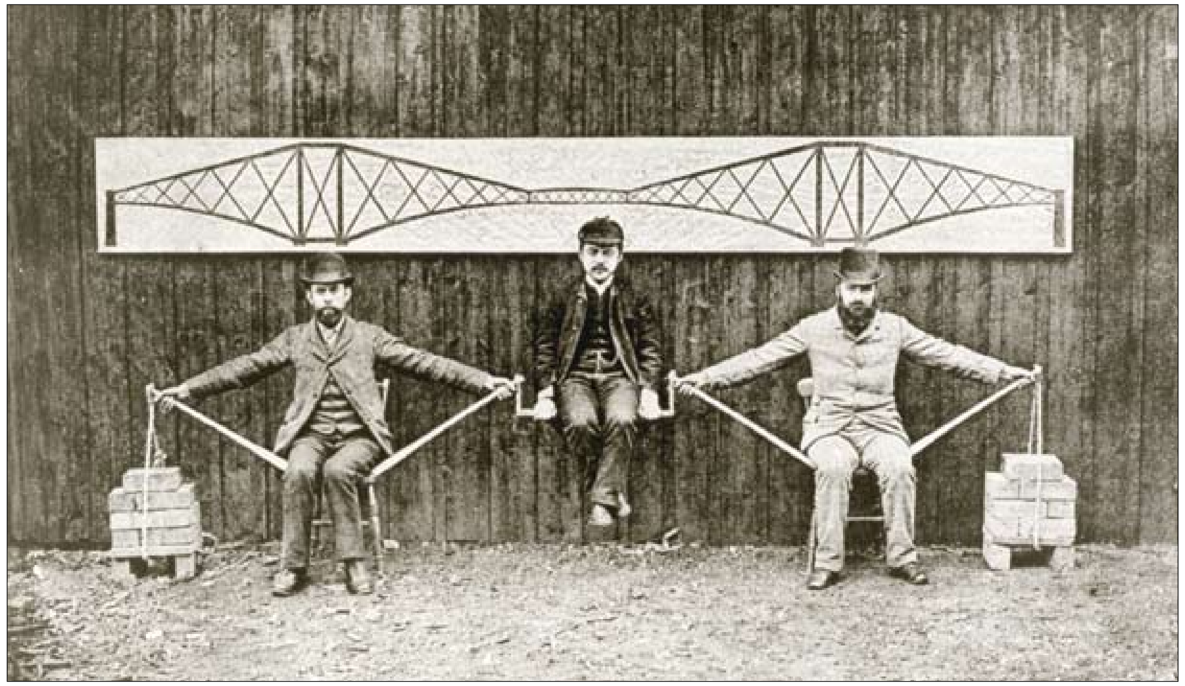
BRIDGES

- **The Forth Railway Bridge**
- Firth of Forth, Queensferry
- 1883 - 1890
- Two main spans of 521 m each
- The longest span in the world at the time
- 54,160 tons of steel used
- A technical wonder

The Forth Railway Bridge is regarded by many engineers as the greatest bridge in the world. With the longest spans in the world at the time of its opening, it was designed in the aftermath of the Tay Bridge disaster of 1879 which engendered a major loss of confidence in Victorian engineering. The bridge took seven years to build between 1883–1890, and its opening by the Prince of Wales on 4 March 1890 was a triumph which did much to restore public confidence in Britain's engineers.

The need for the bridge was a result of a quest by the railways for a shorter route to the north. At the location of the bridge at Queensferry the Forth narrows to a channel little more than a mile wide, which is divided into two by the island of Inchgarvie. The two channels are over 200ft deep and were regularly used by major naval vessels entering Rosyth, requiring a headroom at the bridge of 150ft. Thus the design requirements were for a bridge having two main spans of nearly 2,000ft crossing each of the two channels, whose depth made foundations in mid-river impossible. The largest railway bridge hitherto constructed in the UK was Robert Stephenson's Menai Bridge, which had twin spans of 460ft, but any bridge designed for the Forth at Queensferry would require spans nearly four times as great, a daunting prospect.

Human cantilever



The Forth Railway Bridge

A design involving the cantilever principle was devised by consulting engineers John Fowler & Benjamin Baker of Westminster. The engineers proposed mild steel for the bridge superstructures and this again was an innovation for a major bridge. The bridge also made extensive use of tubular members in compression, many of them of unprecedented size.

Fowler and Baker were subjected to intense scrutiny as they developed the design. They recorded wind pressures on the Forth, carried out endless tests on the quality of the steel, and left nothing to chance.

The contract for the construction of the bridge was awarded to Tancred, Arrol & Co. The senior parner, Joseph Phillips, had worked on the Great Exhibition Building and had nearly 40 years experience of major projects. William Arrol (later Sir William) took personal charge of the operations, both at his works in Glasgow and at the site. He showed much ingenuity in the design of the plant, including hydraulic riveting machines, cranes and drilling methods, and provided many safety devices for his workers.

The superstructure of the bridge is basically three towers with cantilever arms on each side. The towers are 330ft high above the granite pier foundations, and the cantilever arms are each 680ft long, projecting outwards from the towers. The ends of the cantilevers over the river are linked by suspended spans of 350ft. Clearance for shipping is 150ft above high water.

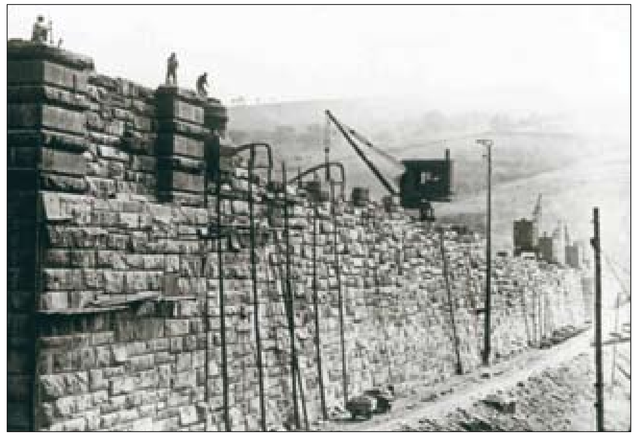
The basic dimensions of the bridge are:

main spans	1,710ft	(521 m)
south approach	10 spans of 168ft	(10 spans of 59 m)
north approach	5 spans of 168ft	(5 spans of 59 m)
overall length	8,296ft	(2,530 m)

There was 54,160 tons of steel used in the construction, and some 6,500,000 rivets. At the peak of construction 4,600 men were employed, and there were 57 fatalities. Electric light was in its infancy but primitive lighting was employed, the first on a construction site. The last rivet (the 'Golden Rivet') was ceremoniously driven by the Prince of Wales at the opening of the bridge on 4 March 1890.

Photo: Robert Cortright, USA

Great Britain



DAMS

- **Vyrnwy Water Supply scheme for Liverpool**
- Virnwy Dam 1881 - 1891
- Vyrnwy Aqueduct
- Thomas Hawksley, G. F. Deacon
- The first masonry dam in the UK

The construction of the Vyrnwy works was authorised by the Liverpool Corporation Waterworks Act in 1880. The original engineer, Thomas Hawksley, was one of the leading Victorian water engineers, and a pioneer of the Health of Towns movement. It was completed by G.F. Deacon. Work began in July 1881 and in 1891 water from Lake Vyrnwy was first sent to Liverpool. The Vyrnwy Dam was the first of a series of masonry and concrete dams. It is a gravity structure 1172ft in length and 161ft in height built in Silurian slates on a buried rock-bar at the end of a lake carved by a glacier and filler with morainic material. The site was chosen in the valley where the moraine covering was least in depth. The two fundamental ideas in this construction were great weight and water-tightness, and great care was taken to achieve these objectives. The mass of the dam consists of large stone blocks. An important feature of the dam was the drainage of the foundations to prevent uplift on the base. It was the first masonry dam to be built in the UK of any size, earth embankment dams being the preferred form.

Water impounded in Lake Vyrnwy in North Wales is then passed down the aqueduct to Liverpool. The aqueduct is some 65 miles long, and in its final form was to consist of three 42in diameter pipes to deliver 40 million gallons per day to the Prescot Service Reservoirs for distribution to Liverpool. The route chosen principally follows the Dee/Severn watershed to maintain high ground until the Mersey and Weaver Basins are reached.

The construction entailed four tunnels, five balancing reservoirs and several river and railway crossings including a tunnel under the Mersey. The pipeline was generally of cast iron for the first phase, although riveted steel was used in the tunnel under the Mersey. This was to facilitate maintenance in the 9ft diameter cast iron tunnel, and marks an early use of steel in trunk mains.

The first three tunnels on the aqueduct, Hirnant, Cynynion and Llanforda, are of similar construction with brick and concrete linings to protect against leakage. The Hirnant tunnel was later duplicated by the Aber tunnel to enable maintenance to be carried out.

At the Oswestry Reservoir where the water is filtered a 510 yards long earth dam provides a reservoir of some 60 m gallons storage. The several Balancing Reservoirs are lined with mass concrete faced with brickwork, or mass brickwork set in cement mortar. The type of construction was varied to suit local conditions.

At Malpas and the Norton Water Tower single tanks of 4.5 m gallons and 650,000 gallons capacity respectively were provided. The reservoirs at Parc Uchaf and Cotebrook were originally intended to be No. 3 tanks of 2 m gallons each, but the two tanks constructed with the first two pipes were found to be sufficient.

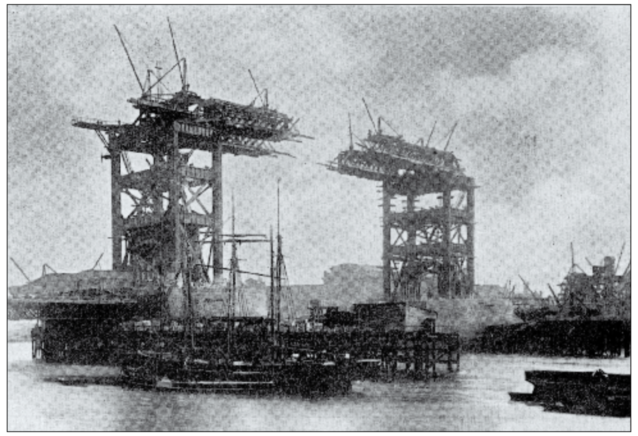
The first section of a third pipe was laid in 1926-1938 in steel, and marked the beginning of the more general use of bituminous coated steel pipes for trunk mains, instead of cast iron which had been used since about 1810. The success of this pipe gave confidence that the corrosion problems associated with steel could be overcome.

After 1946, to increase capacity a fourth pipe was laid upstream of Oswestry to boost capacity. The increase was met downstream of Oswestry by providing booster stations at Bickerton, Norton and Cuerdley.

Great Britain

BRIDGES

- **Tower bridge**
- London
- 1886 - 1894
- Engineer: Sir John Wolfe Barry
- Architect: Sir Horace Jones
- One of the best known bridges in the world



One of the best known civil engineering works in the world thanks to its proximity to the Tower of London, one of the UK's most popular tourist destinations, Tower Bridge was built 1886-1894, and for the best part of a century was the lowest bridge crossing of the Thames. At the time of its construction there was heavy river traffic with extensive warehousing and industry upriver. The Engineer, Sir John Wolfe Barry, designed a complex structure with a two-leaved bascule centre span between towers on river piers. These were founded on deep caissons installed by the contractor John Jackson. The clear span of 200ft could be raised for navigation. The approach spans of 270 ft are a linked suspension bridge continuous through a high level footbridge over main span which masks the suspension chains. The footway, 141ft. in height, was intended to permit pedestrians to cross when the bridge was open, with hydraulically powered lift access. The distinctive towers are steel frames enclosed in masonry, which is mainly granite with Portland stone and hearting of brick. The steel framing is an early example in the London area. The contractors, Arrol, were still involved with the Forth Railway Bridge when work began. The architectural treatment was by Sir Horace Jones, architectural advisor to the City of London. The original steam engines for the hydraulic power were replaced by electricity in 1974. A visitors centre is contained within the bridge.

Tower Bridge, London

Photocredit: Tower Bridge Museum, London

Great Britain

BRIDGES

- **Humber Bridge**
- Between the cities Grimsby and Hull
- 1981
- The longest suspension bridge in the world for 16 years
- Main span 1410 m
- Height of concrete towers 158 m

After leading the world in the art of suspension bridge construction in the early nineteenth century British engineers seem to have avoided this form of bridge for major crossings for nearly a century, the only significant early twentieth century example being that at Chelsea, designed by Buckton and Fereday of Rendel Palmer and Tritton (now HPR). Increasing road traffic lead to a reconsideration of major estuarial crossings associated with a major Motorway and Trunk Road programme after 1945. The long spans involved and navigation considerations meant suspension bridges were back on the agenda. The first to be completed, over the Forth, was a conventional bridge with trussed stiffening girders, but for the Severn a new form of aerodynamically configured box girder was used, significantly reducing the volume of steel required. This revolutionary concept, pioneered by Freeman Fox and Partners, was that adopted for the Humber Suspension Bridge, the longest and last of these bridges. It carries dual two lane carriageways for highway traffic (A15 trunk road) plus a combined footpath and cycle track along each side of the bridge. The reinforced concrete towers rise to 518 ft (158 m) above high water level. The deck structure is of welded stiffened steel plates forming a box 72 ft (22 m) wide and a maximum of 15 ft (4.5 m) deep with panels cantilevering 10 ft (3 m) each side. It is supported by inclined steel wire hangers from the two main cables, each 27 in (0.7 m) diameter, and provides 98 ft (30 m) headroom above high water for ships.

At the time of its opening in 1981 its main span of 4260 ft (1410 m) was the longest in the world, a record it held for 16 years. The north side span is 919 ft (280 m) and the South side span 1739 ft (530 m). It saved ca. 50 miles (80 km) in travel between Grimsby and Hull the major towns north and south of the Humber.

Humber Bridge

Photo: Robert Cortright, USA

Great Britain

CANALS

- **Falkirk Wheel**
- Lowland canals, Scotland
- 2002

British inland waterways have been enjoying a revival and this has stimulated some innovative designs across the network. Falkirk Wheel is the best known example. The Forth & Clyde and Edinburgh & Glasgow Union Canals ceased to be connected when the Falkirk flight of locks (11 x 10ft rise; 110ft rise) on the latter was closed in 1933. In 2002 this connection was restored by means of the landmark 'Falkirk Wheel' boat lift which formed the centrepiece of a £78 million 'Millennium Link' regeneration of the Lowland canals.

The Wheel comprises two 35 m long rotating arms rigidly connected to each end of a 3.8 m diameter central axle 28 m long. The arms support, within semicircular gondolas, two water-filled boat-carrying caissons with double watertight doors at each end. These allow transfer of the boats between the caissons and the aqueduct above and the basin below.

The total weight to be moved is about 1800 tonnes, but the machine is essentially a balanced unit with the loads to be driven by the motors deriving from wind and friction being a small fraction of this figure. There are also loads caused by the unequal balance of water in the gondolas. The drive system, designed to operate with the worst foreseeable combination of these loads, operates by means of ten hydraulic gearbox units driving one end of the main axle. Under normal traffic conditions they rotate the arms 180° in about four minutes.

Each gondola of the Wheel sits in two circular tracks. When the arms are rotated the tendency of wind and friction to move the gondolas out of position is counteracted by the gears at the end of each gondola holding them horizontal and preventing oscillation. Each gondola, which contains about 250,000 litres of water, will transfer up to four boats at a time in about 15 minutes. The design life of the Wheel is 120 years. It is now one of Scotland's most visited tourist attractions.

The project, which includes two locks above the Wheel and one below, and a 168 m sprayed-concrete tunnel under the Roman Antonine Wall and Edinburgh & Glasgow main line railway, was carried out for British Waterways – Director Scotland, Jim Stirling, and designed by Arup Scotland. The contractors were Morrison Bachy-Soletanche. The steelwork was fabricated by Butterley Engineering, Ripley, Derbyshire.

The neighbouring Antonine Wall, or Graham's Dyke as it is known locally, made from ca. 140 – ca. 185 AD, should be mentioned for its major earthworks, the remains of which are still visible in many places. The Wall comprised an earth rampart, ditches, forts and a road and extended over a distance of 36 miles across Scotland from Kinneil to Bowling, more or less on the line of the Forth & Clyde Canal 16 centuries later. One road by which it was served from the south was via Dere Street, from Corbridge via Trimontium (visible from Leaderfoot Viaduct), Inveresk and Cramond. This wall and the better known Hadrian's Wall is part of a World Heritage Site extending across central Europe and embracing a number of Roman defence works.

Falkirk Wheel

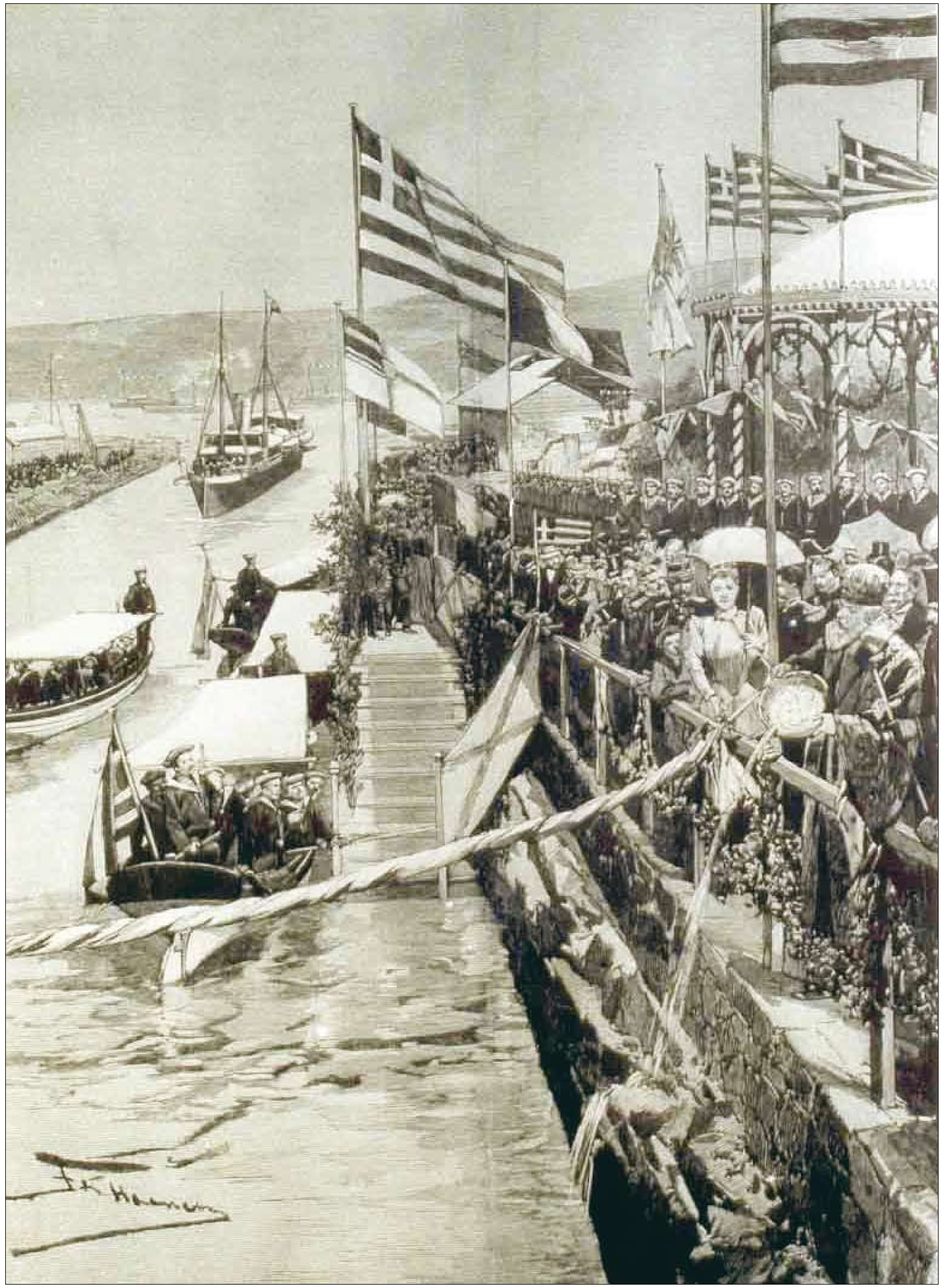
Greece

CANALS

- **Corinth Canal**
- Between the Saronic and Corinthian Gulfs
- 1869 - 1893
- Total length 6,346 m
- 12 million cubic meters of excavated soil

The Corinth Canal lies between the Saronic Gulf and Gulf of Corinth. Due to its special political and economic situation, for hundreds of years the canal was the dream of many governors. The final decision was taken in 1869 by Charilaos Trikoupis (Prime Minister of Greece), and work started in 1882 and finished in July 1893.

The total length of the Corinthian Canal is 6,346 m, with a width at water level of 24.6 m and at the bottom of 21.3 m. The depth of the canal is between 7.50 and 8.00 m. The total volume of excavated soil was 12 million cubic meters.



Greece

Photo: courtesy of Freyssinet

BRIDGES

- **Rion-Antirion Bridge**
- Near Patra (Peloponnesos)
- 1998 - 2004
- The longest multi-span cable-stayed bridge in the world
- 9 international awards

The Rion-Antirion Bridge is currently the longest cable-stayed bridge in the world. It is situated at the crossroads of the two basic axes of the country: PATHE (Petra - Athens - Thessaloniki - Evzonoi) and Ionia Odos (Kalamata - Patra - Ioannina). Due to its geographical position, it is a structure of great significance, joining the Peloponesos with Western Greece, considerably shortening travel time. Moreover, it contributes to the development of bonds between Patra - the third largest Greek city - and the main agricultural areas in Western Greece. The bridge provides a crossing the strait in 5 minutes, in a comfortable, safe and high-quality road environment.

The cable stayed bridge is suspended on 4 large concrete pylons having particular shape. The pylons height over the sea level is 160 m, in total they are higher more than 220 m including also the under sea level part. The soil on which the pylons where layed has been reinforced in advance by insertion of 500 metal pipes.

The suspended deck is made of composite steel-concrete segments which were installed in cantilever on either side of the pylons and suspended step by step with stay cables.

The stay cables (Freyssinet type) are made of galvanised strands with multiple anti-corosion lining. In one stay cable there are at least 72 steel strands with diameter of 15,4 mm.

The Rion-Antirion Bridge is an extraordinary bridge which features a combination of structural resolutions, considerable water depth, strong winds and high seismicity with a possibility of tectonic movements.

General references www.gefyra.gr

Technical data:

Length of suspended deck: 2,250 meters
Suppports: four 160-m-high pylons
Main spans: three spans each 560 m
Length of access to the bridge: 631 m
Cross-section: separated pavement with two lanes per direction
Resistant to winds of up to 250 km/h
Resistance to a 180,000-ton tanker crash
Pier diameter: 90 meters
Earthquake resistance: 7.0 on the Richter Scale

Photo: courtesy of Freyssinet

CONSTRUCTION COMPANY
Kinopraxia Gefyra

Partners in Kinopraxia Gefyra:
- VINCI Construction Grands Projets; 53%
- Aktor A.T.E.: 15,48%
- J&P Avax S.A.: 11,20%
- Athena S.A.: 7,74%
- Proodeftiki S.A.: 7,74%
- Pantechniki S.A.: 4,84%

SUPPLIERS AND PRINCIPAL SERVICE PROVIDERS
- Stay cables: Freyssinet (VINCI)
- Steel framework: Cleveland (UK) and Metka (Greece)
- Prestressing: GTM Construction (VINCI)
- Water-proofing and road surfacing: Eurovia (VINCI)
- Electrical and electronic equipment: VINCI Energies
- Marine handling: Smit (The Netherlands)
- Instrumentation: Advitam (VINCI)

ARCHITECT
B. Mikaelian (Paris)

DESIGN STUDIES
- VINCI Construction Grands Projets
- Ingerop (Paris)
- Geodynamique Structures (Parsi)
- Domi (Athens)
- Consultants: J. Combault, M. Virlogeux

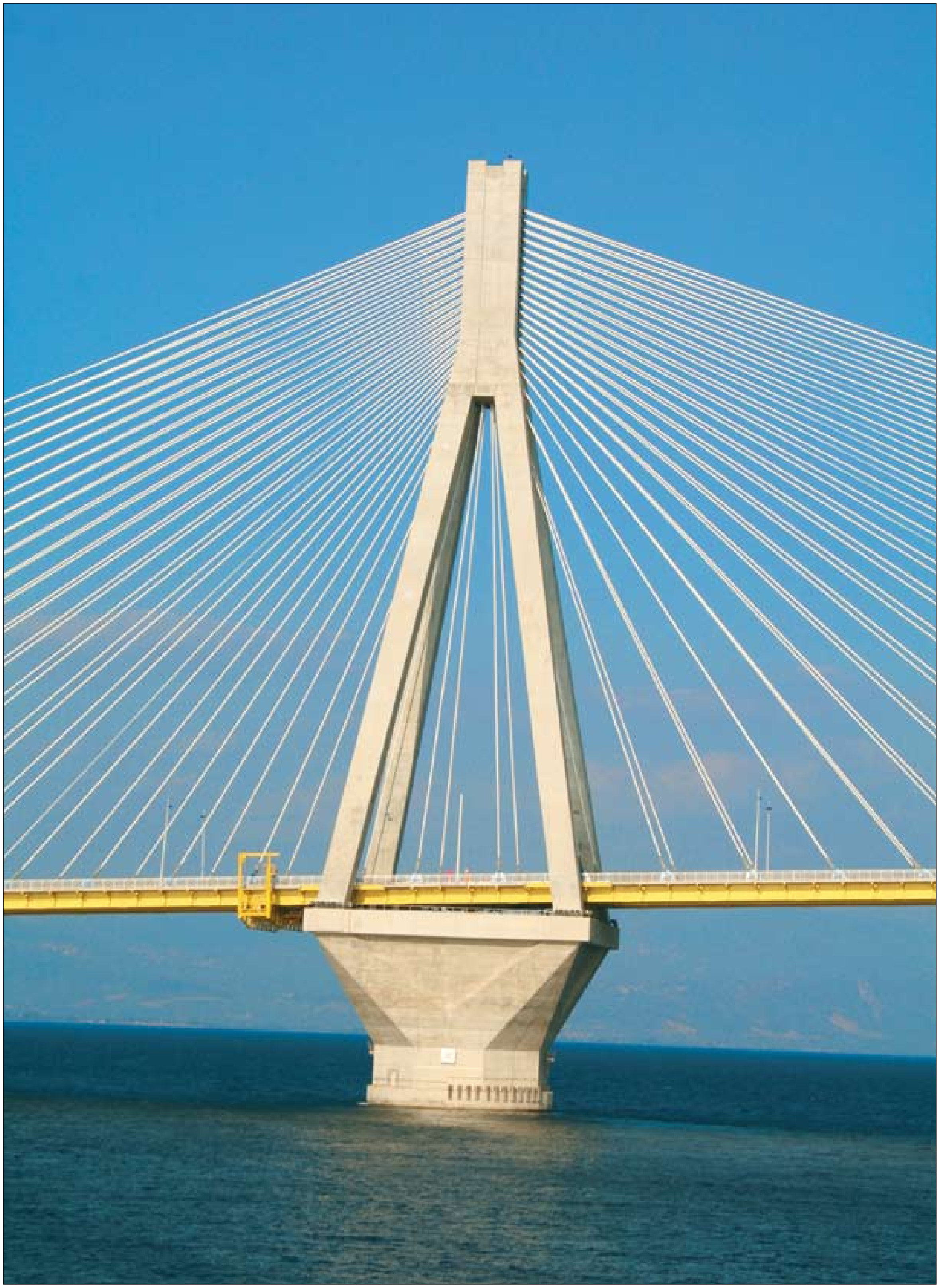


Photo: Andrej Košir, Slovenia

Rion-Antirion Bridge

Photo: courtesy of Freyssinet

Greece

RAILWAYS

- **Athens Metro** (Attiko Metro)
- Athens
- 1993 - 2009 (still under extension)
- More than 650,000 passengers daily
- Over 1000 archaeologichal finds are exhibited in the Metro
- Designed to serve more than 1,500,000 passengers daily

The Metro constitutes the most significant transit and environmental project intended for improving the quality of life in Athens, providing rapid, safe and comfortable daily transportation services to 650,000 passengers, along with a unique journey through the history of the ancient capital.

Currently in the 31 stations of Lines 2 and 3 of the Athens Metro (51 km long), passengers are given the opportunity of getting acquainted with the classical civilisation of Greece and to admire over 1,000 archaeological finds exhibited in especially configured areas within and outside the central stations of the network.

It was this unique 'particularity' of the Athens Metro to exhibit aqueducts, Roman baths, statues, amphorae, coins, artefacts of daily life, etc. for the first time in public that made Greek citizens and foreign visitors not just transfer to the Metro in order to reach their destination but rather selecting it for their main means of transport.

The construction of this major project commenced in early 1993, and the first section of Lines 2 and 3 (15 stations - 15km) was commissioned in January 2000. Nowadays, the second phase of the network's extension is in progress; soon, another 10 stations along with 8.5 km of new line will be added to the Metro system. At the same time, the Ministry of PEHODE and ATTIKO METRO S.A. have already put out to tender the new extension of Metro Line 3 (6 Stations - 7.5 km), which will connect the great port of Greece, Piraeus, with Athens International Airport.

Moreover, a new line, Line 4, with an overall length of 21 km with 20 modern stations, is at an advanced design stage and is anticipated to be tendered in 2009. The construction of this line will offer Athens a 4-line network with a total length of 113 km with 90 modern stations, which will serve more than 1,500,000 passengers on a daily basis.

Finally, it is worth mentioning that two tunnel boring machines are working full-speed in the city of Thessaloniki, the second major city of Greece, in order to construct 13 stations and 9.6 km of line. These stations will be similar to those of the Athens Metro in terms of aesthetics and will be constructed using state-of-the-art technology and the most demanding specifications in terms of safety and operability.

Greece

RAILWAYS

- **Athens (SKA) - Athens Airport Railway Line (Attica Suburban Railway)**
- Athens
- 2004 - 2006
- Designed for a speed of up to 140 km/h

The new double-track railway line from SKA (Acharnai Traffic Center) to Athens El. Venizelos Airport, totalling 32 km, is located in the median of the Attiki Odos Tollway and forms part of the Attica Suburban Railway. It includes the stations of Metamorfossi, Iraklio, Neratziotissa, Kifissias, Pendeli, Doukissis Plakentias, Pallini, Kantza and Koropi.

The construction of this new line included all necessary infrastructure (trackwork, signalling, electrification and telecommanding) works required to develop a modern railway section designed for speeds of up to 140 km/h. The first phase of construction (Olympic phase) was completed in July 2004 and full commercial service was launched in December 2006. The journey time between Athens and the airport is approximately 30 minutes.

Greece

RAILWAYS

- **Athens (SKA) - Kiato Railway Line**
- Athens
- 2005 - 2007
- High-speed railway line
- 105 km-long double-track railway line

The SKA (Acharnai Traffic Center) - Kiato line is a new 105 km-long double-track high-speed railway line which is part of the Attica Suburban Railway. It is also the first section of the Athens - Patra main rail corridor. Part of the line, totalling approximately 13 km, has been constructed in the median of the Attiki Odos Tollway. This new line required implementation of a series of infrastructure (trackwork, signalling, electrification, telecommanding and telecommunication) works, with a view to developing a modern section of the PATHE rail corridor, designed for speeds of up to 200 km/h after Thriassio Pedio.

Along the new railway line, the following structures have been constructed: five tunnels totalling 8,900 m (including 1,450 m of cut & cover sections), railway bridges totalling 1,400 m, 60 road overpasses and underpasses totalling 1,600 m, and nine stations at Ano Liossia, Aspropyrgos, Magoula, Nea Peramos, Megara, Kineta, Agii Theodori, Corinth and Kiato, with subterranean passageways and parking areas. Two new railway stops are foreseen at Zephyri and Zevgolatio, and electrification of the rail corridor is underway. The entire line is in operation and the SKA - Kiato journey time is approximately 60 minutes.

Corinth Railway Station

N. Peramos Railway Station

Greece

RAILWAYS

- **Athens (SKA) - Kiato Railway Line**
- Coastal bridges
- 2005

On the new SKA - Kiato Railway Line, two multi-span bridges have been constructed (one submarine and one coastal), 260 m and 156 m long. They were founded in the sea, at an average depth of about 30 m, in foundation shafts that became piers. The bridges' superstructure is built of prestressed prefabricated 26 m corbels, constructed using the 'on the bed' technique and placed with launching equipment (Caro Varo).

Greece

RAILWAYS

- **Athens (SKA) - Kiato Railway Line**
- Isthmus Bridge
- 2005
- Crossing the Corinth Canal

The new Isthmus Railway Bridge of Corinth Canal, 230 m long, is part of the new SKA - Kiato Railway Line. The bridge connects the Peloponnesos to mainland Greece. It has been constructed using the cantilever method. The bridge's superstructure is a continuous girder of three spans of 60+110+60 m, made of prestressed concrete (B45), with a provision to use external prestress tendons, a box-type cross-section, a deck slab 12 m wide and variable height (ranging from 5 m in the middle of the central span and at the abutments to approximately 11 m at the two piers).

The bridge's superstructure at the piers uses a seismic isolation system, consisting of bearings and dampers, able to absorb a considerable part of the design earthquake energy in order to reduce movement and forces at the bridge's piers to acceptable limits. The piers are founded in shafts with diameters from 6 m to 7 m and lengths from 12 m to 25 m. The foundation is reinforced with a pile-group of nine piles, with a diameter of 1.50 m and length about 15 m.

RAILWAYS

- **Evangelismos - Leptokaria Railway Line**
- 2004 - 2008
- Designed for 250 km/h
- Implementation speed 200 km/h

The new double-track high-speed railway line between Evangelismos Railway Station and Leptokaria Railway Station, totalling 35 km, includes the construction of tunnels totalling 9,759 m (including cut & cover structures), bridges totalling 380 m, 19 grade-separated crossings, railway stations and a parallel road network without any level crossings. The line is part of the Athens - Thessaloniki main rail corridor. This new line deviation required the implementation of a series of infrastructure (trackwork, signalling, electrification, telecommanding and telecommunication) works, with a view to developing a modern section of the main rail corridor of Greece, PATHE / P (Patras - Athens- Thessaloniki - Eidomeni / Promachonas). The line is designed for 250 km/h and the implementation speed is 200 km/h.

Part of the new double-track Evangelismos - Rapsani line section is the area of Tempi Tunnel, an approximately 6.8 km-long section where the pioneering RHEDA slab track system was used for the first time in Greece. The project has reduced journey time by 15 minutes and improved the safety, operational and traffic conditions of the trains while increasing line capacity and timetable reliability.

Greece

TUNNELS

- **Tempi Tunnel**
- 2004
- Pioneering RHEDA slab track system
- Excellent ride comfort

The Tempi project includes four tunnels totalling 5,083 m, of which 1,075 m are cut & cover structures. The main Tempi Tunnel totals 4,035 m, the net cross-section of all tunnels is 82 m^2, designed for a train speed of 250 km/h, while the track axis distance is 4.50 m.

Tempi Tunnel was constructed using the slab track method, which is a pioneering system for Greece. Slab track is a new track system in which the ballast, the load-bearing member of the track, and the sleepers are replaced by a layer (slab) of concrete. The main advantages of the slab track method are that it provides excellent ride comfort, due to the geometric accuracy of the track, and that it requires very low maintenance costs which quickly offset the high installation cost in comparison to conventional ballasted track.

TUNNELS

- **Platamonas Tunnel**
- 2004
- Archaeological finds

The Platamonas project includes tunnels totalling 4,183 m, of which 1,646 m are cut & cover structures. The net cross-section is 82 m^2, designed for a train speed of 250 km/h, while the track axis distance is 4.50 m. The tunnel was constructed mainly with underground methods, but the cut & cover technique was used as well.

When works begun in the area of Platamonas Castle, the Archaeological Service closed several areas in order to conduct archaeological excavations, which have brought to light a large number of antiquities. The tunnel was built with the assistance of state-of-the-art measuring instruments, such as vibrometric seismographs, static and dynamic crack meters and cathetometers. Flood-control works were also constructed in the area of Platamonas for the protection of the railway line and the wider project area.

Greece

RESTORATION

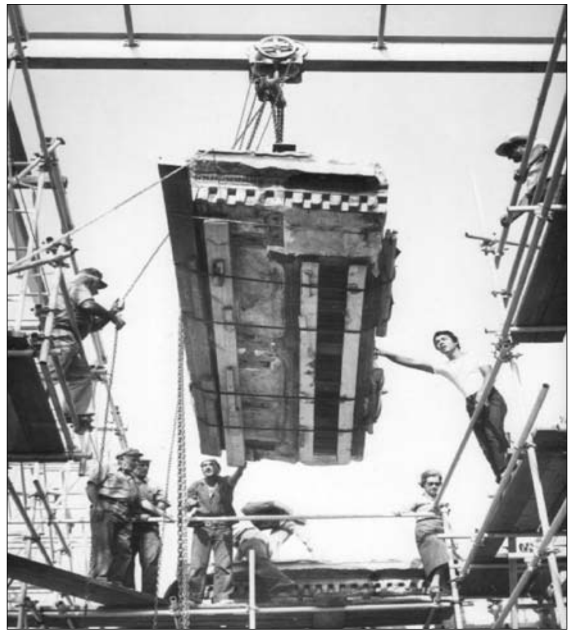
- **Civil engineering in the restoration of the Acropolis monuments**
- Athens
- 1975 - still under restoration
- World monument of humanity and architecture
- Most visited tourist attraction in Greece

Written by Costas Zambas, Dr. Civil Engineering

Civil engineers usually deal with new structures. Repairing of existing structures is really a developing branch of civil engineering, but the restoration of monuments, mainly the province of archaeologists, is a very rare occupation for a civil engineer. In the systematic effort of Greece for the restoration of the Acropolis of Athens during the last four decades, civil engineers played an important role in the activities of the Committee for the Preservation of the Acropolis Monuments (CPAM) in the management, study, research and execution of the whole project.

In this report the author, who had the chance to contribute to this enterprise from the very beginning in 1975, looks back at the first restoration project on the Erechtheion (1979-1986), which is an example of intervention on an ancient monument of inestimable value.

The Erechtheion is a fine Ionic temple with an innovative and compound plan. It was built between 421 and 406 BC, and burned in the beginning of the 1st c. BC but later repaired around 25 BC. It was transformed into a Christian church in the 6th c. and into a residence later on. It was gradually ruined



Transportation of the slab of the roof of the porch of the Karyatids (7 tons)

One of the Karyatids on the way to the Acropolis Museum

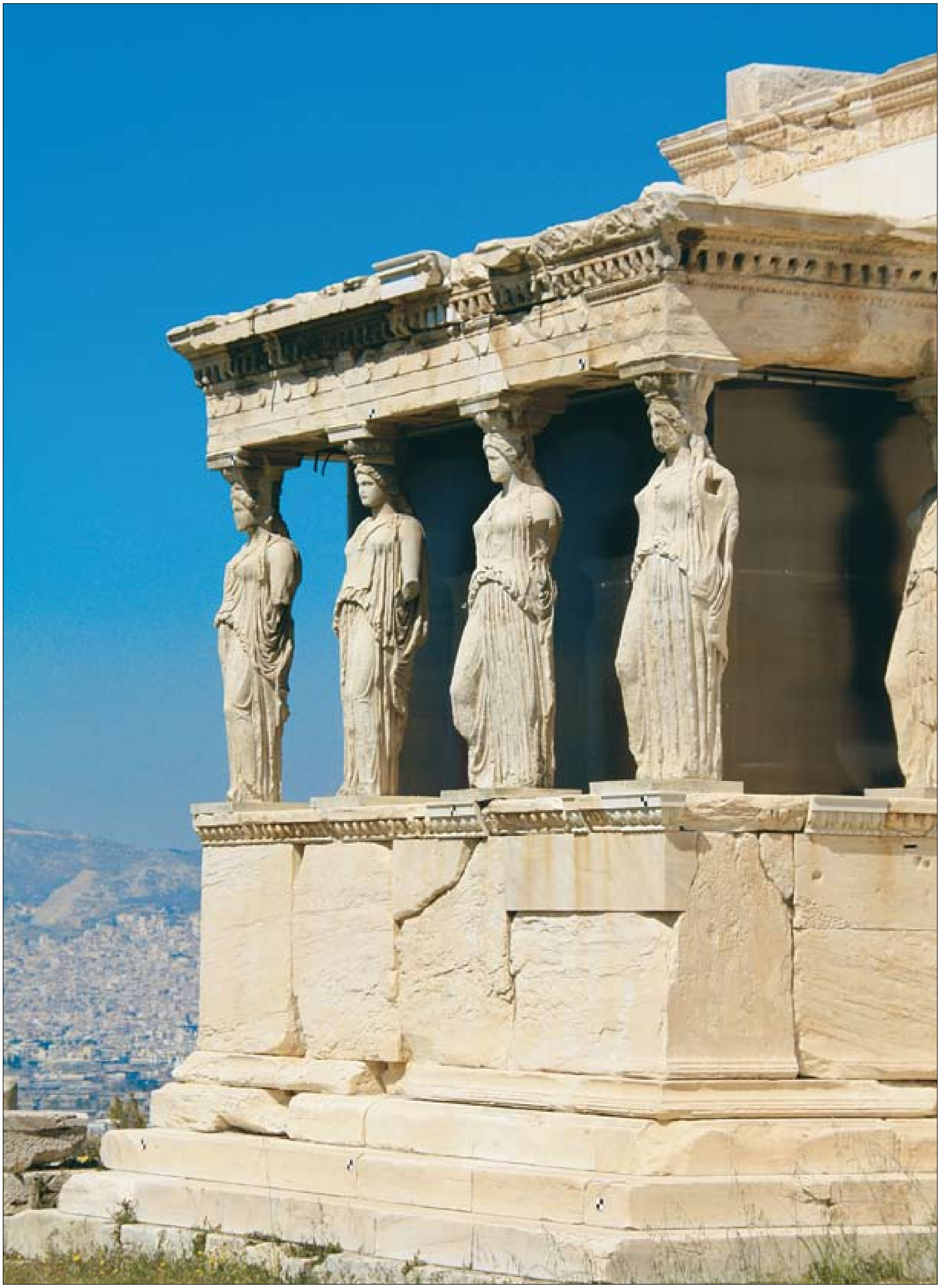


Photo: Gorazd Humar, Slovenia

after the 18th c. It was partially restored in 19th c. and from 1902 to 1908 a major restoration took place. All the walls and the porch of the famous Karyatids were recomposed from the fallen architectural members, with additions made of new marble and with extensive use of steel connecting elements (clamps, dowels, beams, columns, etc). Two kinds of problems made a new intervention by CPAM inevitable: structural damage produced by the oxidation of the steel elements inserted into the building and deterioration of the surfaces of the Karyatides caused by atmospheric pollution.

CPAM was formed in an interdisciplinary way: distinguished archaeologists, architects, a civil engineer and a chemical engineer worked together in a permanent way and established a technical office with a similar composition to perform the study for the intervention. The architects of the office made the survey and drawings of the monument (under the guidance of Prof. Ch. Bouras), the civil engineers the structural checks (Prof. S. Agelides) and the chemical engineers a survey of the deteriorated surfaces (Prof. Th. Skoulikides). The studies were presented before the intervention at an international meeting of experts. It was decided to dismantle all the vulnerable parts of the building (especially the previously restored ones), to repair each element and reassemble the whole according to the original scheme.

The work area was designed and organised in an appropriate way for the site atop the Acropolis Hill, with difficulties in transportation and erection of massive new structures. Scaffoldings made of light steel tubular elements were constructed around the building and four bridge cranes were placed on them to lift the marbles of the building. The south wall, opposite the Parthenon, was the first to be dismantled. The heavy marble slabs of the roof of the Porch of the Karyatides (weighing 7 tons) were carefully removed and lowered to the ground. The five original sculptures of the Karyatids (the sixth was taken by Lord Elgin and is in the British Museum) were encased and transported to the Acropolis Museum.

More than 1000 architectural members were dismantled, and rusted iron components cleaned and reconnected again using titanium parts. The material was proposed by Prof. Skoulikides, but a great many calculations and experiments were needed from the civil engineer's point of view for dimensioning the elements. For replacement of lost parts, new piec-

Photo: Gorazd Humar, Slovenia

Restoration of the Acropolis

The architect in charge of the restoration, A. Papanikolaou (right), the chief marble technician N. Skaris (middle) and civil engineer C. Zambas (left)

es were shaped in order to be applied exactly to the broken surfaces. For the calculation of stresses, finite element analysis was applied.

The Karyatids were replaced by replicas. Inside them and inside the gaps of the marble architraves from the past restoration, a new titanium framework was constructed to support the heavy marble roof.

Beyond the pure civil engineering work, one of the first uses of computers was the rearrangement of the stone blocks of the south wall, taking into account detailed measurements of their geometric characteristics.

For seven years, supervision of the works was an everyday task for the architect in charge, A. Papanikolaou, the civil engineer C. Zambas and the chief marble technician N. Skaris under the constant guidance of CPAM. The restored Erechtheion was given back to the public in 1986. The declaration of the Charter of Venice (1964), suggesting that 'the conservation and restoration of monuments must have recourse to all the sciences and techniques which can contribute to the study and safeguarding of the architectural heritage' found its full implementation in the restoration of the Erechtheion. In this project, civil engineering played an important role. In the other restoration works on the Acropolis that followed the 'CPAM method' in the Parthenon, the Propylaia and the Temple of Athena Nike, civil engineers continued to contribute full time, developing calculation methods and practical solutions for the interventions. A special bibliography was created for this specific field of civil engineering.

DAMS

- **Evinos Dam**
- River Evinos, near Agios Dimitrios
- 1992 - 2001
- Height of the dam 127 m

The Evinos Dam is the most recent dam in Greece. Its construction started at 1992 and finished at 2001. The surface area of the reservoir is 3.5 sq km and its watershed area is 350 sq km. The maximum capacity of the reservoir is 140 million m^3 of water. The earth fill dam is 127 m high.

Greece

HIGHWAYS and ROADS

- **Greek motorways**
- The largest Greek infrastructure project -still under construction

Greece lies in the south-eastern part of Europe and covers an area of 131,952 km^2. The mainland territory extends to 105,834 km^2 (80.2%), while the island territory measures about 26,123 km^2 (19.8%). Greece is a mountainous country that lies at an average elevation of approximately 500 m.

The Ministry of the Environment, Physical Planning and Public Works is the body which elaborates and forms the country's infrastructure policy, as well as the planning and implementation of interventions pertinent to environmental protection. The ultimate scope of the Ministry's activities is the sustainable and integrated development of the country.

The Ministry is responsible for the design and construction of major infrastructure projects in Greece, including the development of transport infrastructure networks.

Over the last years, significant improvements on the Trans-European Road Network (TERN) of the country have been made, based on a strategic plan for the development of all transport infrastructure. The plan aims at developing and modernising TERN infrastructure to facilitate the transport of passengers and goods, as well as productive, tourist and other activities in the country.

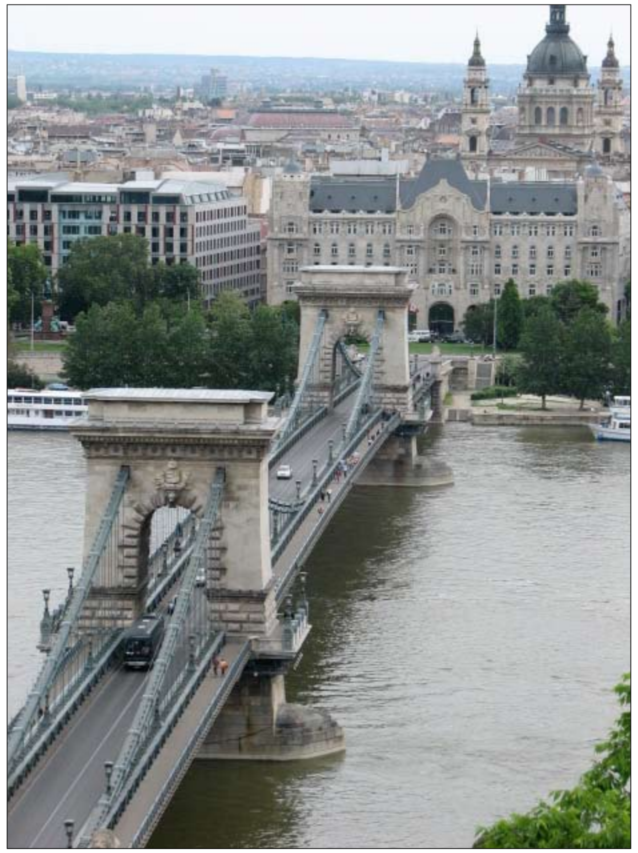
As far as functionality is concerned, the design of TERN projects is intended to ensure satisfactory network capacity, an increased level of road safety and a reduction in transport time and cost. Therefore, most TERM sections have been designed as motorways or at least as expressways.

Special emphasis has been placed on:

a) the conversion of the PATHE (Patra-Athens-Thessaloniki-Evzoni) road axis to a motorway, given that the PATHE axis is the most important in the country, traversing areas that gather 60% of the country's population and 70% of its economic activity;

b) the construction of Egnatia Odos, a new motorway that runs east-west through Northern Greece from Igoumenitsa (the large harbour on the Ionian Sea) and that will contribute decisively to the development of Northern Greece (especially the regions of Ipiros, Macedonia and Thrace), while the same time it will function as the "collector road axis" of Balkan and South Eastern European transport.

Hungary



BRIDGES

- **Chain Bridge (Lanc Hid)**
- Budapest
- 1839 - 1849
- Outstanding historical bridge
- Main span 202.6 m

Technical data:

Length: 380 m
Span sizes: 88.7+202.6+88.7 m
Width: 14.5 m
Width of the traffic lane: 6.4 m (originally 5.4 m)

Mass of steel structure:
- original bridge: 2146 tons
- renewal of the bridge: 5194 tons
- reconstruction of the bridge: 5000 tons

Time of construction:
- construction: 1839-1849
- renewal: 1913-1915
- reconstruction: 1947-1949

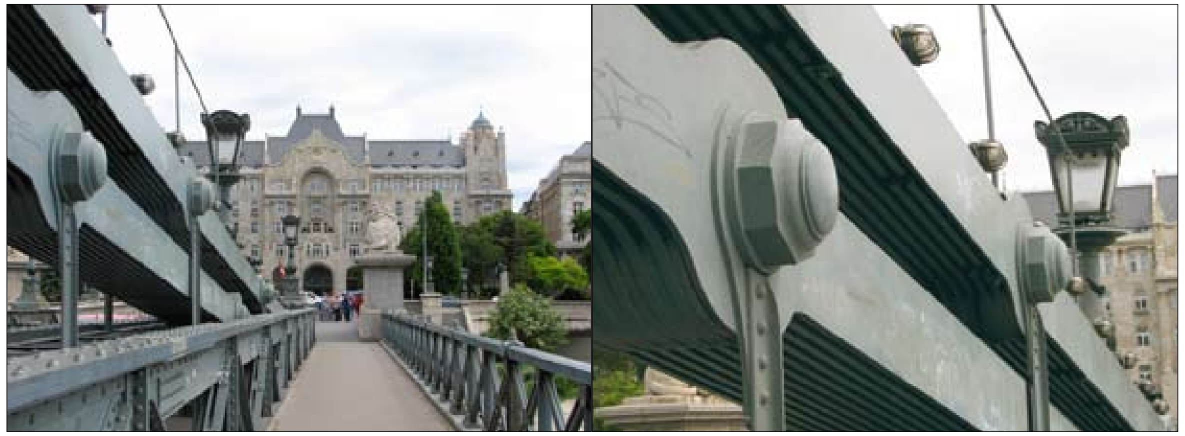
The first bridge connecting the western part of Hungary to the east was constructed in Budapest between 1839 and 1849. The bridge was the first common project of the two cities Buda and Pest, which were separate cities at that time, only united in 1873. The bridge can be considered one of the most advanced construction projects of its time. It was the first bridge constructed over the 2400 km-long Danube river south of Regensburg (Germany). The bridge could not have been constructed without the help of Count István Széchényi, the 'greatest among Hungarians', who offered one year of his income to found the Academy of Sciences in Hungary and set up the 'Foundation for a Bridge' in 1832. Act XXVI of 1836 finally made the construction of the bridge official.

The bridge was designed by William Tierney Clark, the well known engineer from England. This decision was important in the later collaboration between Hungary and Britain. Construction started in 1840; the site supervisor was a Scot, Adam Clark (no relation to William Tierney Clark). The foundation of the bridge was the most sensitive part of the work. The bases of the pillars were surrounded by three lines of piles while water was pumped out. The first pile was driven on 28 July 1840, and this part of the work was finished in August 1842. The ceremony for laying the foundation stone of the bridge was held on 24 August 1842, in the presence of the Palatine of Hungary and more than one hundred guests, on the very bottom of the Danube.

The final heights of the two pillars are 55 m and 60 m. The chain elements were manufactured at Hunter & English, and the cast iron supporting elements were fabricated in Hungary, at the iron works of Count Andrássy in Dernő (today Slovakia). The iron parts of the bridge were transported from England to Hungary over the Main-Danube channel in Germany, which had been reconstructed in those days. The chains were constructed quickly; work started on 28 March 1848 and was finished by 18 July in the same year. Because of the War of Independence against Austria, construction of the bridge slowed down. The Austrian army tried to destroy it, but this was averted by Adam Clark. At last the construction was finished and the bridge was opened on 20 November 1849. Count Széchényi never saw the bridge, one of his greatest dreams, in operation, whereas Adam Clark could enjoy it, since he ended up settling in Budapest.

During the Second World War, among the other bridges of Budapest, the chain bridge was blown up by the German army. It was reconstructed and newly opened on the 100-year anniversary of its first inauguration on 20 November 1949. The Chain Bridge and its surroundings today belong to the heritage of Budapest.

Text: G. Szőllőssy



Chain Bridge, Budapest

Photo: Robert Cortright, USA

Hungary

RAILWAYS

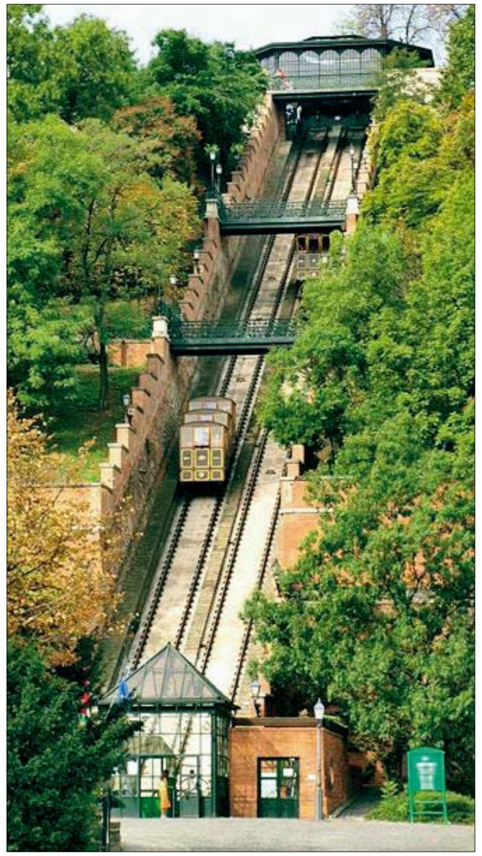
- **Buda Castle Funicular**
- Budapest
- 1870
- Second funicular railway in the world

Count Ödön Széchényi (1839-1922) presented his petition for construction of a steam-engine funicular to the responsible office of the capital in 1867. The castle of Buda at that time served not only as a military stronghold, but most of the government offices and institutes and the seat of the Parliament had shifted from Pozsony to Buda, along with the Hungarian theatre and several palaces and religious institutions, so there was heavy demand for a modern public vehicle instead of walking or using expensive dog-carts. The 5 November issue of the daily Pester Lloyd reported the plan of the steam elevator. There was an enthusiastic report on this new way of transport to the castle, showing the technical solution as well. The article described the technical principle of a pair of carts connected by an iron chain, running together, one cart going down while pulling the other up. In order to balance the difference of the load of the carts, there would be a small steam engine on the downhill station. The plans were submitted by Ödön Januszek, engineer to the Committee for Making the City Beautiful on 21 February 1868.

The site, just below the castle, was the most important square in the city at that time, since there was the Buda port at the only bridge between Buda and Pest, the Chain Bridge, completed in 1849. All the main roads to the north and south, and even to the west, after the handover of the tunnel below the Castle Hill in 1857, started from this point. The Southern Railways station, which opened in 1861, could be reached through the tunnel, as well as the terminus of the first horse-drawn tram in Buda. People said that all roads started from and led to this place. Even today you can find the starting point of all of the main roads of Hungary here, the “0” km point (today: Adam Clark Square).

Count Ödön Széchényi was 23 years old when he was appointed representative of the government for the 1862 World Exhibition in London. He had a great interest in new technical solutions and made every effort to make use of these for the interests of his country. He founded and equipped a voluntary association as the fire service of the capital. Later he sailed to Paris from Budapest on the Danube on a 6 horsepower steamship and on the channels connecting the Marne to the Danube. They say that he had seen a steam lift on this journey, which gave him the idea for the steam funicular. He also wanted to construct a cog-wheel railway to Sváb Hill in Budal. At that time (1862), there was only one funicular railway in the world, in Lyon. The one constructed in Buda became the second.

The downhill station was designed like a romantic country house, and all the machinery was disposed here. According to the design the starting point could be reached by a seven-step stair. The authorities had not given permission to construct an uphill station for military reasons. Wooden bridges were built at the crossings of the railway and the causeways of the park, built in 1840 on the eastern slopes of the hill. These bridges were later replaced by beautiful iron structures. Count Széchényi had gotten the right to construct and operate the funicular for 40 years, which right was later transferred to a shareholder company founded by him. The capital fixed its right to all the technical equipment after the expiry of this permission, according to the rights connected to any mass transit systems in Budapest in the 19th and early 20th century, like the horse-bus, the omnibus, the cog-wheel railway, the tram and bus services. The military treasury acquired the ‘right to destroy’, which meant that if the funicular were destroyed in a war or uprising, there would be no claim for compensation.



The construction was started by the designer in 1868 and led by engineer Henrik Wohlfarth from 1869. Perhaps for safety reasons he changed the slope of the funicular from 32.5° to 30°. As a result of this the downhill starting point was raised from 1.5 m to 7.5 m and instead of 7 steps, 35-40 steps were necessary to reach it. This was considered the most anachronistic solution of the funicular in a technical examination in 1912. The smoke coming from the chimneys of the beautiful downhill building was also very unpleasant. A detailed report by Wohlfarth can be found in the bulletin of the Association of Hungarian Engineers regarding the construction and technical solutions of the funicular in 1870. The article was taken over by most of the important technical journals of the world. Luckily sketches were added to this article, which can be considered today a very valuable and extraordinary technical document, together with the deeds of assignment kept in the city archives, since the original plans of the construction have been lost.

We see from the paper that a 30 HP steam engine was installed in the basement of the downhill station, at the foot of Castle Hill, with two 15” diameter cylinders and a 6” cast iron drive axle; the tapered drive wheel was made of cast iron; the two cast iron tumblers have a diameter of 9’ each; on one side the wire rolls down, while on the other side it rolls up; on the uphill station there was a 9’ diameter turning wheel for the wire rope, fixed to the two carts. There were two steam engines installed, with one working continuously and the second as a back-up. The wire rope was rolled from six bunches, each having 6 strands, with a hemp rope in the centre.

The Schulz Machine Factory from Vienna supplied the steam engines, while the boilers were made by Első Magyar Gépgyár (First Hungarian Machine Factory) and the wires came from Fischer St. Egiday. (The boilers were changed to ones made by Ganz in 1893.) There was a special iron structure with springs installed on the carriage of the carts for safety, for catching them between wooden girders in case the wires broke. Wohlfarth explains that official tests were made with twice the design load of the carts, cutting the wires at various points along the track, and the carts were caught by the safety system in every case. The full length of the track was 106 m, and the lifting height was 50 m. There was a normal-gauge 1435 mm track made of Vagnol rails, weighing 14.6 kg/m. The carts were made by Spiering Maschienen und Wagenbaufabrik in Vienna, adjusted to the 30° slope with three cabins. Six passengers could sit in the first class cabin in the middle, and six passengers in each of the second-class cabins on both sides.

The funicular was opened after 16 months of construction on 2 March 1870. At the beginning its capacity was 900 passenger/hour/direction. The funicular was run by one fireman, one mechanic and 3 conductors. The carts were not supposed to stay at the station longer than five minutes, but if any passenger with a season ticket arrived, they had to start immediately. At the time of the 1896 World Expo, the funicular carried 670,000 passengers. The only accident occurred in the same year, but not because of a technical failure. It happened that a large group of reporters, considerably more than 24 people, asked the fireman to carry them down after closing time. The fireman, not being well trained, did not brake the cart properly, and the speeding cart ran into the wall, causing a number of injuries, of which the worst was only a broken leg. There were 1.8 million passengers in 1919, while the maximum, 2.1 million, was reached in 1943. The waiting time was 3 minutes maximum. Ticket prices were reduced in 1937, causing not only a considerable increase in traffic, but also income, which should be instructive, even today.

Ownership of the funicular was shifted to the City of Budapest in 1920. It was planned to carry out a degree of modernisation on it, but it remained the same system with the steam engines and the original carts on the original rails till American bombing destroyed it on 20 December 1944, leading to a 42-year-long shutdown. The damage was not terribly serious, but the political leadership of the city had not kept the funicular up-to date, so they decided not to reconstruct it. The engines were dismantled and removed in 1947, but the rails were left, overspread by vegetation.

Within the framework of the Scientific Association for Traffic, a Committee for the Funicular was founded in 1966 in order to reconstruct the funicular as a technical monument and city attraction. Luckily, instead of modernisation, the funicular was reconstructed in its original form, but the resolution for the reconstruction only came into force in 1984. The works started in the same year. The greatest technical change was shifting the engines and other machinery to the cellar of the uphill station. The welded rails were reconstructed on a reinforced concrete slab, and instead of steam engines, electric engines were installed. The carts were reconstructed according to their original 19th century form, for 3x8 passengers. The starting point of the funicular was shifted up to the level of Adam Clark Square, and thus the steps were no longer necessary. The drive rope was made in six pieces, each consisting of 36 strands of steel wire, calculated with a safety factor of 9. The capacity of the DC electric engine is 54 kW. The funicular was reopened on 4 July 1986.

Important data:

Track length: 101.00 m
Lifting height: 50.50 m
Slope: 30°
Speed of carts: 10km/hr (3m/s)
Travel time: 43 sec
Track gauge: 1435 mm
Distance of the axles: 2900 mm
Diameter of the turning wheel: 2900 mm
Diameter of the drive rope: 29 mm, 3.14 kg/m
Net weight of the cart: 6000 kgs
Passenger load: 24x80 kgs

Hungary

BRIDGES

- **Mária Valéria Bridge**
- Between Esztergom and Párkány (Sturovó)
- 1893 - 1895
- Destroyed twice

Technical data:

Length: 496 m, 5 spans
Width of the traffic lane: 9.5 m (originally 7.2 m)
Mass of the steel structure: 2500 tons
Time of construction:
- construction: 1893-1895
- first destroyed: 1919
- renewed: 1927
- second destruction: 1944
- reconstruction: 2000-2001

There has been a historical connection between Esztergom and Párkány since 170 AD. The legions of the Roman Empire at the time of Marcus Aurelius crossed the Danube here. Later, in 1075, Esztergom became the seat of the Kings of Hungary, and since this time there has been a regular connection between the two sides of the river.

After finishing the Franz Joseph Bridge in Pozsony (Bratislava), the Parliament ordered the construction of a new bridge on this site. There was a tender for the construction of the bridge and on 23 February 1894 construction started. The design and preliminary works took only 4 months. The bridge was designed by János Feketeházy. The highest point of of the main girder of the bridge is 14 m, and a total of 18,000 m^3 of various kinds of stone was used for construction of the pillars, while more than 400,000 bolts were used on the girders. Construction went on day and night; at the pillars, 14 m deep, electric lights were used. By the end of 1894 all the pillars had been finished, and the bridge was set into operation on 28 September 1895, named after the daughter of Franz Joseph, Marie Valeria, born in Buda. At the end of the First World War, on 22 July 1919, the bridge sustained an explosion, damaging it seriously. It was, however, reconstructed by 1927.

Unfortunately, the German army destroyed the bridge on 26 December 1944. Although the river was cleared by 1947, there was no political will to reconstruct the bridge. Discussions between the Hungarian and Czechoslovakian authorities started in 1964, but there was no decision. So, in order to save the steel structure from corrosion, the Hungarians started to demolish the concrete structures of the bridge in 1993. There was a lot of discussion on both sides of the river about the possibility of reconstructing the bridge. The matter became an important issue with the change of political regimes, since the two truncated bridge heads represented a memento of unfulfilled desires.

At last the Hungarian and Slovakian governments agreed on the reconstruction, and with the signing of a bilateral agreement in 1999, the reconstructed bridge was set into operation on 11 October 2001. Today it symbolises the connection between the two countries and the people on both sides of the Danube.

Text: G. Szőllőssy

Hungary

HYDROPOWER PLANTS

- **Hydroelectric Power Plant at Gibárt**
- Hernád River
- 1903
- Technical monument since 2004
- Still running with the original machinery

There were 38 hydroelectric power plants in Hungary at the beginning of the 20th century, of which three can be found in the present territory of Hungary. These power plants were set into operation on the Rába River at Ikervár in 1895 and at Szentgotthárd in 1897, and on the Hernád River at Gibárt in 1903. The energy of the Hernád had been harnessed for water mills for hundreds of years, so by the end of the 19th century, on the river below Kassa, there were at least 20 mills, but most of them were dismantled early in the 20th century. Hydroelectric plants were constructed at the sites of such former mills, near the village of Gibárt, from 1902 to 1903, and at nearby Felsődobsza on 1912.

The flow of the Hernád River, swelled by a wattle dam, had been shifted to an artificial mill channel, forming a small island. The dam at the northern edge of the island and water mills on both arms of the river can be seen on a map from 1856. After finishing the hydroelectric plant, one of these mills was run with electric power till 1932, when its machines were dismantled, and later, in 1934, the building was demolished.

The 19th Hungarian hydroelectric plant was designed in 1901, at a point 60+180 km on a curve of the Hernád, at the small village of Gibárt, which later, in 1985, became part of the smallest town in Hungary, Encs. Count János Harkányi (1859-1938), landowner, economist and politician, minister of trade from 1913 to 1917, built the plant on the site of one of his mills. He wanted to supply his fields and villages, and his modern agricultural plants about 30-40 km from here in Taktaharkány, Megyaszó, Hernádnémeti and Szerencs, with electric energy. For this reason he founded the office of the Gibárt Electric Co. in one of the most elegant streets of Budapest, with an operational seat in Szerencs. The power plant was connected to the centre of the land (Jajhalom, 35 km away) with a 12kV transmission line in the same year it was set into operation, and from this point, with the use of transformers, a 17.5 km-long 3kV transmission line provided energy to the farm. A steam engine driving a three-phase generator was run by the boiler of the distillery in the centre of the farm, giving any additional electric energy to the main grid via the 12 kV lines from Gibárt. After setting this network into operation, there was increasing demand for electric energy, to connect more and more villages to the network, and so the capacity of the plant was extended and a new three-phase generator, connected directly to a 294.4 kW Diesel engine, was mounted in. The machinery supplied electrical needs from 1908 to 1934. Count Harkányi sold the power plant and 50% of his shares to RVKVSZ in 1920. A 12kV transmission line connecting the Gibárt and Felsődobsza hydroelectric plants was built in this year, opening the possibility of cooperation with the Electric Works Co. of Miskolc, which was the owner of this nearby power plant and other thermal power plants as well. The Gibárt power plant was nationalised in 1948, and since 1963 has belonged to the Electric Supply Co. of Northern Hungary.

The original designs of the power plant disappeared, or were lost, after nationalisation. Even the names of the designer and contractor are unknown. The hydroelectric power plant was built with a head canal. The 635 m-long canal starts at the dam, on the right side of the river. A wooden bridge on piles was constructed in order to protect the dam from ice and debris. This bridge had been damaged several times, and was finally demolished in 1957. A waste was constructed 100 m from the dam, situated between the head canal and the down-water part of the river. The waste had four shuttles, with a 12 m opening. The decayed shuttles were changed to steel ones in 1998, when a new service bridge was constructed.

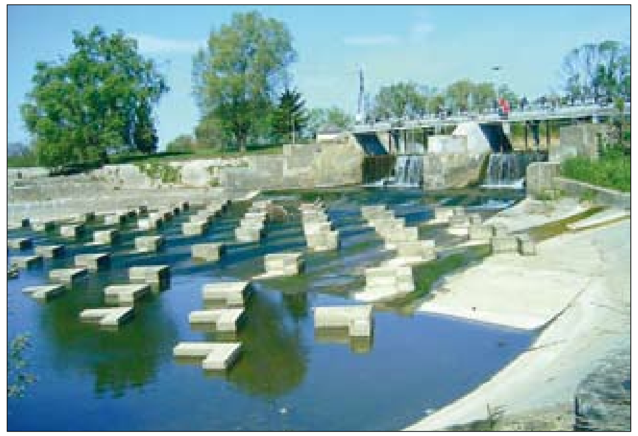
The dam was constructed with two 13.5 m openings, divided with piles. Both openings are divided into three parts with a double-table iron dam (3x4.5 m). This iron structure can be sunk to the bottom during the break-up of ice. The dam stood undamaged during an onslaught of 1m-thick, 100-200 m^2 slabs of ice during the spring floods of 1958.

The originally hand driven tables of the dam are running with electric power today. They were changed in 1982, while the monitoring system and automatic working mechanism were set up in 2001. The dam was constructed at a time when the water level of the Hernád was low enough to diverge it. It has a foundation made of concrete. The piling was made of stone, strengthened with a slightly reinforced concrete. This was changed to an 8 cm-thick reinforced concrete structure, made of bauxite concrete in 1937. Since this type of structure loses its strength within 20-25 years in Hungary, the reinforced concrete coat was renewed in 1963. The openings of the dams were found to be too small, because of the heavy floods. These floods represented a continuous danger to the dam and its surroundings. This was further increased because of the regulation of the Hernád in Czechoslovakia after 1920 and the construction of dams against floods along the Hungarian section of the river, which were finished by 1950. Both the dam and the waste were not enough to handle the maximum runoff water. In order to solve this problem, a new 32 m-wide waste was constructed between the island and the dam in 1960. (The water reservoir constructed above Kassa at Ruzsin in 1968 gives further security to the Gibárt power plant.)

The engine house is at the halfway point of the head canal. The house is made of brick pillars and has a terraced roof. The five windows with curves and the façade constructed just behind the pillars give an extraordinary shape to the building.

The energy of the water is utilised by two Francis turbines, having a running wheel with horizontal axis, manufactured by the Ganz Machine Factory. Both have 294.4 kW of power. The diameter of the running wheels, each with 15 blades, is 940 mm. The wheels were changed in 1929, at the time of changing the phase of the AC supply from 42 Hz to 50 Hz. The first repair of the turbines was done in 1947. The general overhaul of the turbines was done from 1967 to 1969, after 64 years of running without any problems. This work was done by Ganz-Mávag. The turbine blades are regulated by an oil-hydraulic regulator, made by Ganz. One of them is still the original, while the other was replaced in 1943. The generators of the power plant were considered to be of the highest and most up-to-date quality at the time

Hydroelectric Power Plant at Gibárt



of their construction by the Electric Factory of the Ganz Co. (At the beginning of the 20th century there were usually small DC plants only.) The power output of the three-phase 400 kVA generator was 12kV, at 19.3 A. The designer of the "O"-type generators was Otto Titusz Bláthy, one of the inventors of the transformer. The manufacturing of this type of generator started in 1898, on the machines in Gibárt; they were set into operation in 1902. The machines are still working well.

The Gibárt hydroelectric power plant is the oldest plant in Hungary in its category of size and type, running with the original machinery, even today. During its 100 years of running it has functioned well, generating more than 250 million kW of electricity. The power plant is part of the heritage of Hungary, and as such was declared a technical monument in 2004.

Technical data:

Height difference: 4.4 m
Runoff: 18 m^3/sec
Performance: 500 kW
Two 13.5 m openings
240 m-long upstream canal
Generated power: 2.5 million kWh/year

Text and photos: Csaba Holló

Hungary

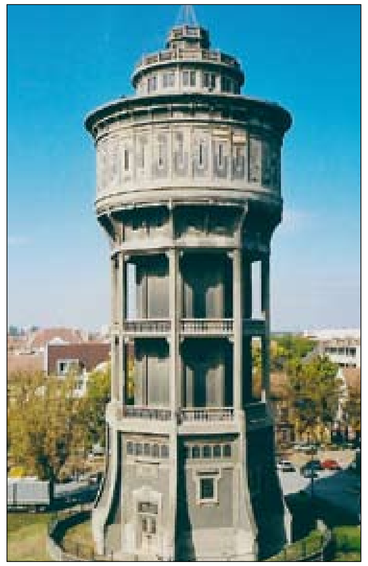
TOWERS

- ■ **Szeged Water Tower**
- ■ Szeged
- ■ 1904
- ■ First reinforced concrete water tower in Hungary

Water supply for cities is an essential issue, all over the world. Szeged, a city on the Tisza River, started to construct its first water lines in 1862. The line, which supplied a large part of the city, was finished by the next year. This was a very important step in the struggle against epidemics, but after only a few months the pump filters were already filled with silt, and instead of regular cleaning, the water was pumped without any filtration.

The flooding of the Tisza destroyed the town in 1879; only 200 out of 6000 houses were saved. After the reconstruction of the city, water was drawn from deep wells. The use of the wells helped till 1903, when a tender was issued for the design and construction of a high-capacity water tower. There were altogether 14 entries. The most interesting one was submitted byy Szilárd Zielinszki. He was the first doctor of science in the field of engineering and a professor at the Technical University of Budapest, later the first president of the Hungarian Chamber of Architects and Engineers in 1923 and the 'father' of reinforced concrete construction in Hungary. He proposed constructing both the tower and the tank from reinforced concrete. His bid for the design and construction was the lowest, and this was a big problem for the decision-making authorities, since the solution was unique. There had been no water tower constructed with this technology at that time in Hungary, and the first Hungarian Standard of Reinforced Concrete Structures was not issued until 6 years later. After many arguments, the application was approved by a decision of the Assembly of the Town on 13 June 1903.

The water tower was finished in late December 1904, and the tank was first filled with water on 26 November 1904. The whole site was empty during this process – only Zielinszki waited there, standing just below the tank, for the successful result. The water tower of Szeged was the largest ever constructed from reinforced concrete in Europe in 1904.



Technical data:

The tower has two main parts: the tank, with a capacity of 1000 m^3, and the reinforced concrete structure supporting it at a height of 31 m. The 15.4 m-diameter tank is 6.40 m high, with a wall thickness of 15 cm at the bottom and 10 cm at the top. This type of shell structure only came into basic use in the world after 1930. The water tower is still in operation. There was no major damage during the wars, but some reconstruction was done in 1960. After a century, both the structure and the tank had to be reconstructed. Thanks to the city, the state and other resources, the reconstruction was completed in 2007. A special decision was taken by the city of Szeged to form a Pantheon of Engineers around the tower. Four statues of engineers who had played a great role in the life of Szeged have already been inaugurated. The reconstruction of the water tower of Szeged won the Tierney Clark Award, founded jointly by the Institute of Civil Engineers (Great Britain) and the Hungarian Chamber of Engineers.

Hungary

BRIDGES

- **Pentele Bridge**
- Dunaújváros
- 2004 - 2007
- Main span: 308 m

Text: Adrián Horváth,
lead designer in charge,
FŐMTERV Ltd.

The Pentele Bridge over the Danube is located in Dunaújváros, about 70 km south of Budapest. The bridge was designed to accommodate major European traffic demands of the North-South and West-East corridors, linking the west and east geographical formations of Hungary.

The whole bridge consists of two access bridges and a main (river) bridge. The full length of the bridge is 1682.55 m, the left side access bridge 300 m, the main bridge 307.9 m, and the right side access bridge 1065 m. The access (flood area) bridges extend in a 7000 m-radius curve and tie to the straight main bridge section with a transition curve. The carriageway runs from 40 m high with a slope of 1.46% to the level land on the left riverbank.

The main part of the bridge is a basket-handle tied arch bridge with parallel cables. The size, structural solution and erection method of the bridge required preliminary research and advanced design methodology. Innovative technologies were applied to build the foundations, the access bridges and the main bridge.

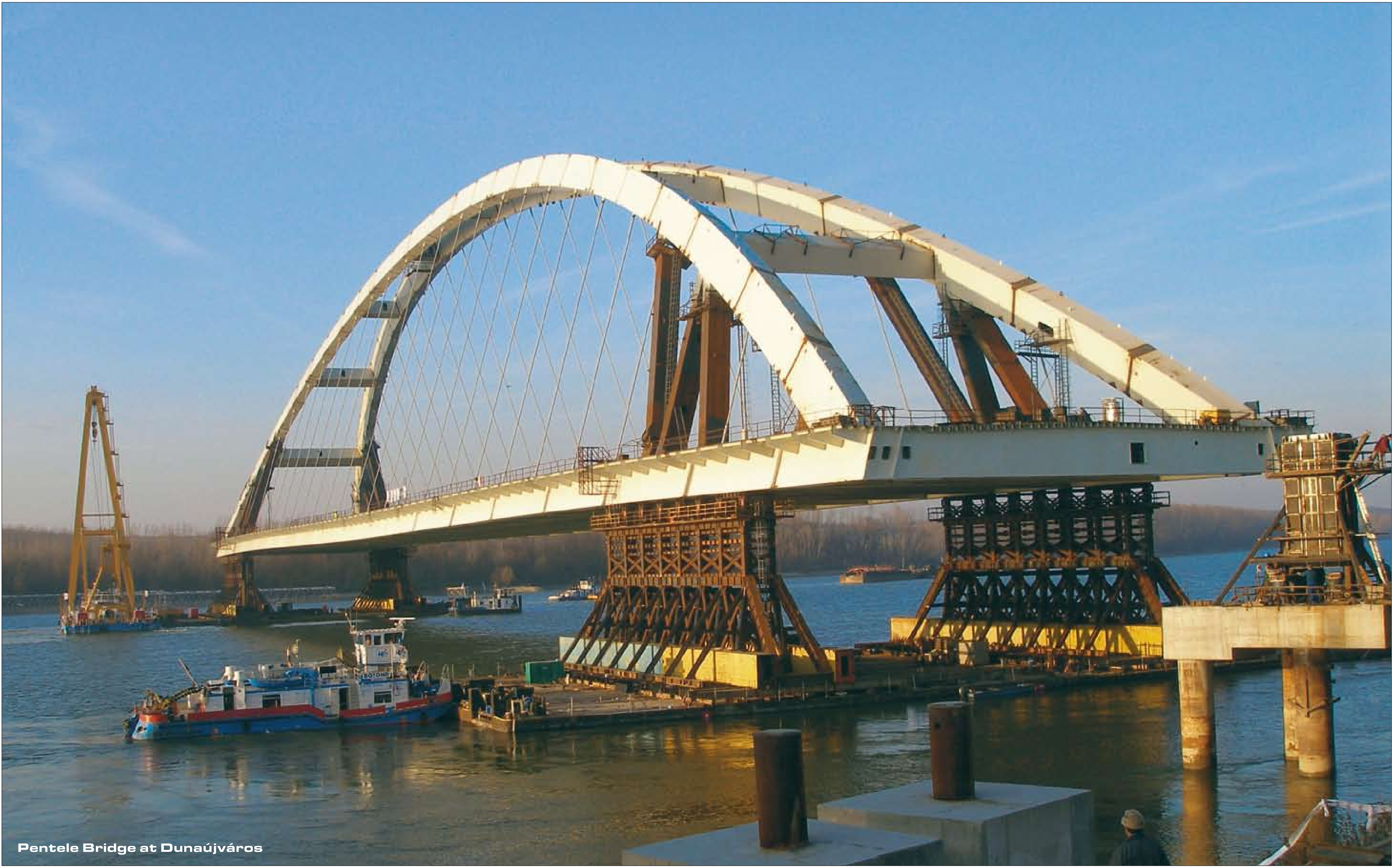
The 87,000 kN arch bridge was floated on barges in one piece to its final position from an assembly area on the left bank. The total floated weight, including scaffoldings, was 105,000 kN. The steel box girder superstructures of the right bank access bridge were erected by incremental launching from the Danube. A floating crane lifted the 17 m-long, full cross-section assembly units onto an auxiliary yoke provided between supports No 13 and 14. The units were welded in full cross-section. Launching started here towards abutment No 1. A so-called by-pass bridge supported the front end of the structure. To assist completion of the river bridge foundation, barrier elements were placed in the river in order to create a dry site for the workers.

Design and construction data

Design: 2002-2004
Construction: 2004-2007
Service date: 23 July 2007
Material used:
- structural steel: main bridge: 7699 t; approach bridges: 14,000 t
- reinforced concrete: 51,200 m^3
- piles: ϕ150: 7100 m, ϕ80: 700 m
- painted surface (arch bridge): 99,300 m^2, app. 140 tons
- waterproofing: 57,000 m^2

Total cost: EUR 187 million

Owner: State Motorway Management Co. Ltd. (ÁAK Zrt.)
Client: National Infrastructure Development Corporation (NIF Zrt.)
Contractor: Dunaúj-Híd Consortium of Vegyépszer Pte. and Hídépítő Corp.
Designer: FŐMTERV Civil Engineering Designer Ltd.
Architect (substructures and handrails): Kertész Építész Stúdió (Kertész Architectural Studio), Dunaújváros



Pentele Bridge at Dunaújváros

Photo: courtesy of Freyssinet

Ireland, Republic and Northern

Introduction

Author of the texts: Ron Cox

Ireland's long history of construction ranges from ancient burial mounds, ring forts and round towers, to medieval stone bridges, lighthouses and water supply.

Irish engineering in the eighteenth century was closely linked to new and improved communication and transport systems. The first large-scale canal project (**The Grand Canal**) commenced in 1755 and was completed in 1804.

In maritime structures, the important early nineteenth century work of the Rennies at **Dun Laoghaire Harbour** set the standard for many other harbours around the country. As an island, the country is ringed by navigational aids, in particular lighthouses, the best known being the **Fastnet Rock Lighthouse**. Of Ireland's many bridges, one of the most iconic is the **Liffey Bridge** in Dublin, opened in 1816 and recently restored to its former glory.

Civil engineering construction was essential in the provision of electrical energy to serve a developing economy, the building of the hydroelectric power station to harness the fall of Ireland's longest river (**The Shannon Scheme**) and the pumped-storage station at **Turlough Hill** in the Wicklow mountains being but two examples.

Following the establishment in 1922 of the Irish Free State (later the Republic of Ireland) and Northern Ireland, the engineering of the two jurisdictions tended to develop along separate lines. In the area of public health, the cities of Dublin, Belfast and Cork each developed distinctive water supplies over a long period, with Belfast being partially dependent on a scheme based on the **Silent Valley Reservoir** in Co. Down. The northeast of Ireland, in particular Belfast, developed many indigenous heavy engineering industries, including shipbuilding. **The Thompson Dry Dock** was opened in 1911 to accommodate the RMS Titanic and her sister ships.

RMS Titanic, designed by Igor Antić, Slovenia

Ireland, Republic and Northern

CANALS

- **Grand Canal (Main Line)**
- Dublin - Shannon Navigation
- 1757 - 1804
- The average width of the canal is 9.1 m

In 1715 an Act was passed in the Irish Parliament 'to encourage the draining and improving of the bogs and unprofitable low grounds and for the easing and despatching the inland carriage and conveyance of goods from one part to another within the Kingdom'. The Act marked the beginning of the canal age in Ireland.

In 1757, work started on a canal to connect Dublin with the Shannon Navigation (known as the Grand Canal). Following the incorporation of the Grand Canal Company in 1772, work continued and the first 29 km section from the Dublin terminus at City Basin to Sallins in County Kildare was opened to traffic in 1779.

The canal crosses the River Liffey by the Leinster Aqueduct and continues to its summit level at Lowtown about 85 m above low water at Dublin. It had been planned to cut straight across the Bog of Allen, but John Smeaton advocated a more northerly route towards Edenderry, which was adopted. Smeaton had argued with William Chapman about the desirability or otherwise of draining the bog prior to cutting the canal. Smeaton's view prevailed and the canal was constructed at the same level as the existing surface of the bog, without allowing for a period of drainage. The result was that the land on either side drained into the canal and subsided, leaving the canal confined by high embankments. These have proved to be a constant source of trouble to the canal: major breaches of the banks occurred soon after completion, again in 1916, and more recently in 1975.

The line was opened to Tullamore by 1798 and Tullamore Harbour became the temporary terminus of the canal whilst it was decided how best to reach the Shannon. The route eventually chosen followed the valley of the River Brosna, joining the River Shannon just north of Banagher at Shannon Harbour.

Under the direction of John Killaly, work on the canal continued, sections of bog being pre-drained before construction and the Grand Canal was finally opened to the Shannon Navigation in 1804.

The average width of the canal is 9.1 m and the average depth at the centre is 1.5 m with a minimum headroom under the bridges of 2.6 m at the waterline. The average width of the locks and the navigation under bridges is about 4.6 m. The shortest lock is 21.2 m, the longest 27 m, the narrowest 4.1 m, and the widest 4.9 m. Branches of the canal were completed to Athy (the Barrow Line), and to Edenderry, Kilbeggan and Ballinasloe. The Grand Canal was connected to the River Liffey in 1796 by the construction of the Circular Line from the First Lock at Inchicore to the Grand Canal Dock near Ringsend.

Ireland, Republic and Northern

HARBOURS

- **Dun Laoghaire Harbour**
- Dunleary
- First works started in 1815
- An area of about 100 ha
- The harbour is also a major yachting centre

In 1815, eight harbour commissioners were appointed for the purpose of building a new harbour, eastward of the old fishing port of Dunleary, to replace an earlier pier. The 'Dunleary Asylum Harbour' was intended primarily to provide a safe refuge for sailing ships unable to reach Dublin during heavy winter gales.

The initial design of the harbour consisted of a single pier to be carried out about 853 m from the shoreline, but in 1817, John Rennie was consulted and subsequently proposed two embracing piers, which later became known as the East and West Piers. In the same year the foundation stone was laid and work began. Between 1817 and April 1820, 696 m of the East Pier were completed. Three years later it had reached 1021 m, its final length being 1290 m. The West Pier, begun in 1820, was already 488 m long by 1823, and by December 1827 had reached 1262 m; its final length was 1547 m.

The base of each pier is 94 m wide and constructed with blocks of Runcorn sandstone, each 1.4 cu.m in volume. From 1.8 m below low water and upwards, granite was used. At the top, the pier is 15.8 m wide, with a 12.2 m promenade on the inner side and a 2.4 m to 2.7 m parapet wall to protect the upper promenade from the waves.

The piers enclose an area of about 100 ha. The rock for forming the piers was quarried at nearby Dalkey and transported to the harbour by a funicular railway. The core of the piers consists of granite rubble loosely tipped and allowed to consolidate using the action of the waves.

Following the death of John Rennie in 1821, his son John (later Sir John) Rennie, took over as consultant to the project. He proposed two short projecting arms from the ends of the piers, leaving a narrow entrance of about 137 m. However, when the government Board of Works took over responsibility for the harbour in 1833, they decided on an entrance width of 232 m with rounded pier heads. The present East Pier Lighthouse and Battery Fort were completed in 1860.

Mail packet steamers, on the service from Holyhead in North Wales, berthed initially at a 152m wharf completed in 1837 near the East Pier. They transferred to the Carlisle Pier in 1859 with direct rail connection to the main line to Dublin (the line of the Ireland's first railway, opened in 1834).

A car-ferry terminal was built in 1970 and the rail link finally abandoned in 1981. A major extension to the vehicle and passenger handling facilities was completed in 1995, including a berth for the high-speed catamaran passenger / vehicle ferry, the largest of its type in the world at the time of its introduction in 1996 on the Holyhead-Dun Laoghaire service. The harbour is also a major yachting centre.

Ireland, Republic and Northern

BRIDGES

- **Liffey Bridge**
- Dublin
- 1816
- Cast iron arch spanning 42 m
- Restored in 2002
- Heritage award in 2002

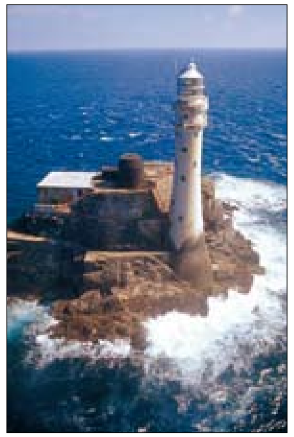
The earliest known iron bridge in Ireland, the Liffey Bridge, was erected in 1816 for pedestrian traffic to connect Merchants Arch on the south quays of the River Liffey with Liffey Street Lower leading from the north quays.

The bridge is a single span cast-iron arch with an elliptical profile and consists of three parallel arched ribs spanning 42 m between angled masonry abutments and having a rise of 3.6 m (The span increases to about 43 m at deck level). Each arch rib consists of six lengths of cast-iron bars of cruciform section. These are connected together at each rib joint to form two tiers of rectangular openings with chamfered surround, the depth of the opening decreasing towards the crown. The ribs are stiffened by the deck and by diagonal and normal bracing to form a truss in the plane of the intrados. The transverse cross members are of hollow circular section with a bolt passing through, and act as spacers to provide lateral stability. Cast corbels on the outside ribs carry a flat plate that supports the parapet railings. The Liffey Bridge was cast at the Abraham Darby III foundry at Coalbroookdale in Shropshire, England and was restored in 2002. The Liffey Bridge won the Heritage Award in 2002.

Liffey Bridge, Dublin

Photo: Robert Cortright, USA

Ireland, Republic and Northern



TOWERS

- **Fastnet Rock Lighthouse**
- Fastnet Rock
- 1848 - 1853
- The most southerly point of Ireland
- The most famous of all Irish lighthouses
- Height of the lighthouse 54.7 m

On a jagged pinnacle of rock, 7.2 km off the Cork coast southwest of Cape Clear, stands the most famous of all Irish lighthouses. The first lighthouse tower on the Fastnet Rock was constructed between 1848 and 1853. This cast-iron tower, supplied and erected by J. and R. Mallet of Dublin, was 19.4 m high, tapering from a diameter of 5.8 m at the base to 4.1 m at the top. It consisted of flanged plates bolted together, the base being secured by long bolts into the rock surface.

The tower was modified in 1867 to make it more resistant to heavy sea conditions, but doubts were raised regarding the stability of such towers, and it was decided by the Commissioners of Irish Lights in 1891 to build a completely new lighthouse on the rock. The old tower was taken down and the lower section converted for oil storage.

Work on the present tower, designed by William Douglass (Engineer-in-Chief to the Commissioners), commenced in 1896 and continued, as weather permitted, until June 1904, when the powerful light was exhibited for the first time.

The tower is built from Cornish granite, each of the granite blocks being dovetailed into adjacent blocks in each ring of masonry. The tower contains 1642 cu.m of masonry weighing 4368 tonnes. The base diameter of the tower is 15.8 m tapering to 12.2 m at a height of 6.1m above the base. Partial rings in this section form the facing to the natural rock face. The total height of the masonry tower is 44.6 m. Including the lantern room, the overall height of the lighthouse is 54.7 m. The operation of the light became automatic in 1989.

HARBOURS

- **Thompson Dock (Titanic)**
- Belfast
- Nov. 1903
- Length of the dock 260 m
- Could be dewatered in 100 minutes
- Transatlantic ship TITANIC was built here

The Thompson dry dock in Belfast was constructed for the Belfast Harbour Commissioners in 1903/11 by Messrs Walter Scott & Middleton of London. The mass concrete design was by the Commissioners staff under the direction of G.F.L.Giles, and incorporated a 1.4 m thick watertight inverted brickwork arch to preclude the porosity problems experienced with the nearby Alexandra dock.

Ireland, Republic and Northern

The dock is approximately 260 m long, 29 m wide and 13 m deep and is located beside the pumping station that serves both dry docks. The Thompson dock could be dewatered in 100 minutes, involving the pumping out of some 95 million litres of water.

The dock was built to accommodate the Olympic Class ocean liners of the Cunard Company and has become particularly associated with the ill-fated RMS Titanic.

At the time of its construction the Thompson dock was the biggest dry dock in the world, built for the biggest ships in the world. RMS Olympic was the first ship dry-docked here in April 1911, followed later by her sister ships Britannic and Titanic.

DAMS

- **Silent Valley Reservoir**
- Belfast Water Supply
- The dam was opened in 1933
- 457 m long earth embankment
- 64 km long pipeline

In 1891, all local sources of fresh water at a level sufficient to serve the higher parts of Belfast having been utilised, consideration was given to possible sources of additional supplies and it was decided to develop a scheme in the Mourne Mountains in County Down to the south of the city.

The catchments of the Kilkeel and Annalong Rivers were acquired and a 64 km long pipeline (including two long tunnels in rock) was constructed to deliver water to a service reservoir near the city. The catchment boundary was defined by a 35 km long rubble wall, built between 1904 and 1922. Completion of the pipeline satisfied immediate needs and deferred the need for a reservoir until 1922, when S. Pearson & Sons were awarded the contract for the building of the Silent Valley Dam. This is an earth embankment 457 m long and 26.8 m high, with a clay core and concrete cut-off trench.

The Silent Valley Dam became something of a ‘cause celebre’ for inadequate site investigation. Boring indicated rock at about 6-15 m, but it was not proven. The contractor started to dig the cut-off trench, but found no rock, only boulders (one of which was described as being as big as a cottage), interlaced with soft clay. Rock was eventually found at 42-61 m below ground level.

In 1928, the contractor was permitted to proceed on a cost plus basis, using a design that relied on the use of compressed air. A series of shafts with a diameter of 3.6 m was sunk. These shafts were filled with concrete to form the cut-off wall.

The dam was opened on 24 May 1933. One highly attractive feature is the concrete bellmouth overflow, installed only after extensive model testing.

Ireland, Republic and Northern

HYDROPOWER PLANTS

- **Shannon Hydroelectric Scheme**
- River Shannon
- 1925 - 1929
- One of the largest of its type in the world at the time

As Ireland was emerging from the Civil War in the autumn of 1922, a young physicist and electrical engineer, Thomas McLaughlin joined the firm of Siemens Schukert in Berlin, where he developed the concept of harnessing the power of the River Shannon to produce electricity. He persuaded the government of the Irish Free State to accept a plan to construct a single hydroelectric power station at Ardnacrusha near Limerick to achieve the most efficient utilisation of the fall in level between Lough Derg and the Shannon estuary.

Equally important to the success of the Shannon Scheme, as it became known, was to be an electricity grid, stretching the length and breadth of the country. Rural electrification was to become the essential framework for the social, economic and industrial development of the country.

The Shannon Scheme, commenced in 1925, involved the construction of a weir and intake, head- and tail-race canals spanned by four reinforced concrete road bridges, and the power station complex itself. The weir across the River Shannon diverts and controls the flow of water into the 12 km long head-race canal. Essentially, the power station consists of an intake sluice house, penstocks, generating building, waste channel and navigation locks. The intake sluice house is built on top of a 123 m long mass-concrete gravity dam across the end of the intake canal. The locks can accommodate vessels up to 32 m in length and there is also a183 m long fish pass.

The Shannon Scheme, one of the largest civil engineering projects of its type in the world at the time it was constructed, was officially opened on 22 July 1929, and by 1935 was supplying around 80% of the country's electricity requirements.

In 2002 the Shannon Scheme joined the ranks of internationally recognised engineering feats when it received two major awards. The awards were presented jointly to Siemens and the Electricity Supply Board. An International Milestone Award was presented by the Institution of Electrical & Electronic Engineers in recognition of the fact that the Shannon Scheme served as a model for other large-scale projects worldwide and because it had an immediate impact on the social, economic and industrial development of Ireland. An International Landmark Award, presented by the American Society of Civil Engineers, commended the Shannon Scheme for the huge achievement in civil engineering and it's contribution to society.

Ireland, Republic and Northern

HYDROPOWER PLANTS

- **Turlough Hill Pumped Storage Station**
- Glendalough, County Wicklow
- 1969 - 1974
- Four 73 MW reversible pump turbines
- The only one of this type in Ireland

Ireland's only pumped storage electricity generating station is situated at Turlough Hill near Glendalough in County Wicklow. It is not a primary producer of electricity, but uses the excess capacity that is available in the national system during periods of low demand - mainly at night - to pump water from a lower reservoir to an upper reservoir. It then uses this same water to produce electricity during periods of high demand.

The scheme was designed by the Civil Works Department of the Electricity Supply Board. The cavern and tunnels were constructed between 1969 and 1974 by a consortium of German companies led by Alfred Kunz & Co., in association with the Irish Engineering and Harbour Construction Co. The station was commissioned in 1974.

The upper artificial reservoir was formed on the top of the mountain by removing many tonnes of peat overburden. Excavated rock was used to form a 25 m high embankment. The lower reservoir was a natural lake, the bed of which was lowered by about 15 m. The mean gross head available at the site is 287 m.

The cavern inside the mountain is 82 m long by 23 m wide by 32 m high and entailed the removal of 47000 cu.m of granite rock. The cavern houses four 73MW reversible pump turbines and the associated generating units. A single steel-lined pressure shaft connects the turbines with the upper reservoir and has an internal diameter of 4.8 m and a length of 584 m at a slope of 28°. The tail-race tunnel has a diameter of 7.2 m and is 106 m long.

Ireland, Republic and Northern

BRIDGES

- **Boyne Bridge**
- 2003
- Main span 170 m, the largest in Ireland
- The largest cable-stayed bridge in Ireland

All photos: courtesy of Freyssinet

The Boyne Bridge is a cable-stayed road bridge having a total length of 360 m. The deck is 33 m wide and made of steel. The main span is 170 m long while the total cable stayed lenght executed with Freyssinet stays is 240 m long. A high pylon having a shape of a letter A was used to support stays in two lines. Anchoring of stays was executed with anchorage type Freyssinet H.D. In total 360 tons of stays were installed to support the deck of the bridge.

Owner: NRA (National Roads Administration) / Meath and Louth County Councils
Engineer: Roughan & O'Donovan
Design: Roughan & O'Donovan
Contractor: SIAC - Cleveland JV Bridge

Latvia

BRIDGES

- **Bridge on the Venta River**
- Kuldiga
- November 1874
- The longest brick road bridge in Europe

This is the longest brick road bridge in Europe. The length is 164 m and the width is 11 m. The bridge has 7 spans, each 17 m long. It was opened on 2 November 1874.

Fredrich Staprans was the author of the arch design and site supervisor, but Otto Dice was the contractor and author of the passage complex. During the First World War (in 1915), two side spans of the bridge were blown up, but in 1926 they were reconstructed according to the design of Pavils Pavulans, a professor at Latvia University.

Latvia

TOWERS

- **10a Alises St. Water Tower**
- Riga
- 1910
- Unique reconstruction of the tower

The water tower, with a 2000 m^3 steel tank, was built in 1910. It has a special reinforced concrete foundation. To improve the water supply, in 1937 the tower was raised by 7.5 m. This operation was very particular and unique in Europe. The work was done by raising the steel tank by jacks and filling the gap with a layer of brick cladding. Then the jacks were supported on that brick layer and the tank raised step by step to the necessary level. During the work the water tank was connected to the water supply system and fulfilled all of its functions.

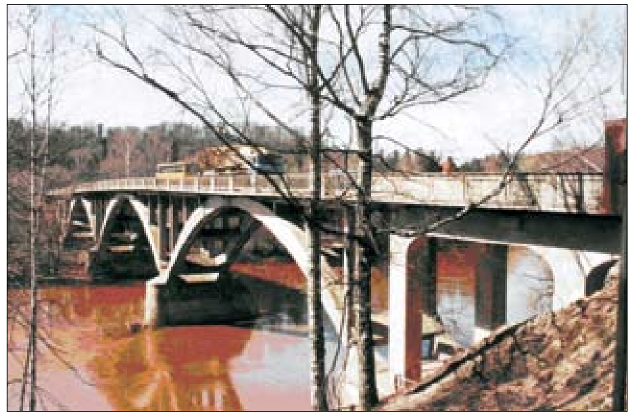
TOWERS

- **21 Gaujas St. Water Tower**
- Riga
- 1913
- An architectural monument of Latvia

The biggest water tower in Riga was built in 1913 in the Art Nouveau style. It has brick walls and a water tank with a capacity of 2000 m^3.

The tower is an architectural monument of Latvia.

Latvia



BRIDGES

- **Bridge on the Gauja River**
- Sigulda
- 1937
- Restored in 1950

A three-span reinforced concrete bridge over the Gauja River in Sigulda was opened for traffic on 23 July 1937. The total length of the bridge is 153 m. The main arch spans are 36+37+36 m long. The width of the traffic lane is 6 m and the width of the pavements on both sides is 1.5 m. The upper part of the bridge was designed by Professor Karlis Gailis. The supports and foundations were designed by K. Tomels.

In the summer of 1941 the Red Army blew up the bridge. It was restored in 1950.

BRIDGES

- **South Bridge over the Daugava River**
- Riga
- Oct. 2004 - Nov. 2008
- The largest bridge in Latvia

Contracting Authority
Riga City Council City Development Department. Head of the South Bridge Unit was Eduards Raubiško.

Designers
The extradosed bridge was designed by the St. Petersburg Design Institute Giprostroimost Sankt-Peterburg (Chief Engineer Igors Koļuševs).

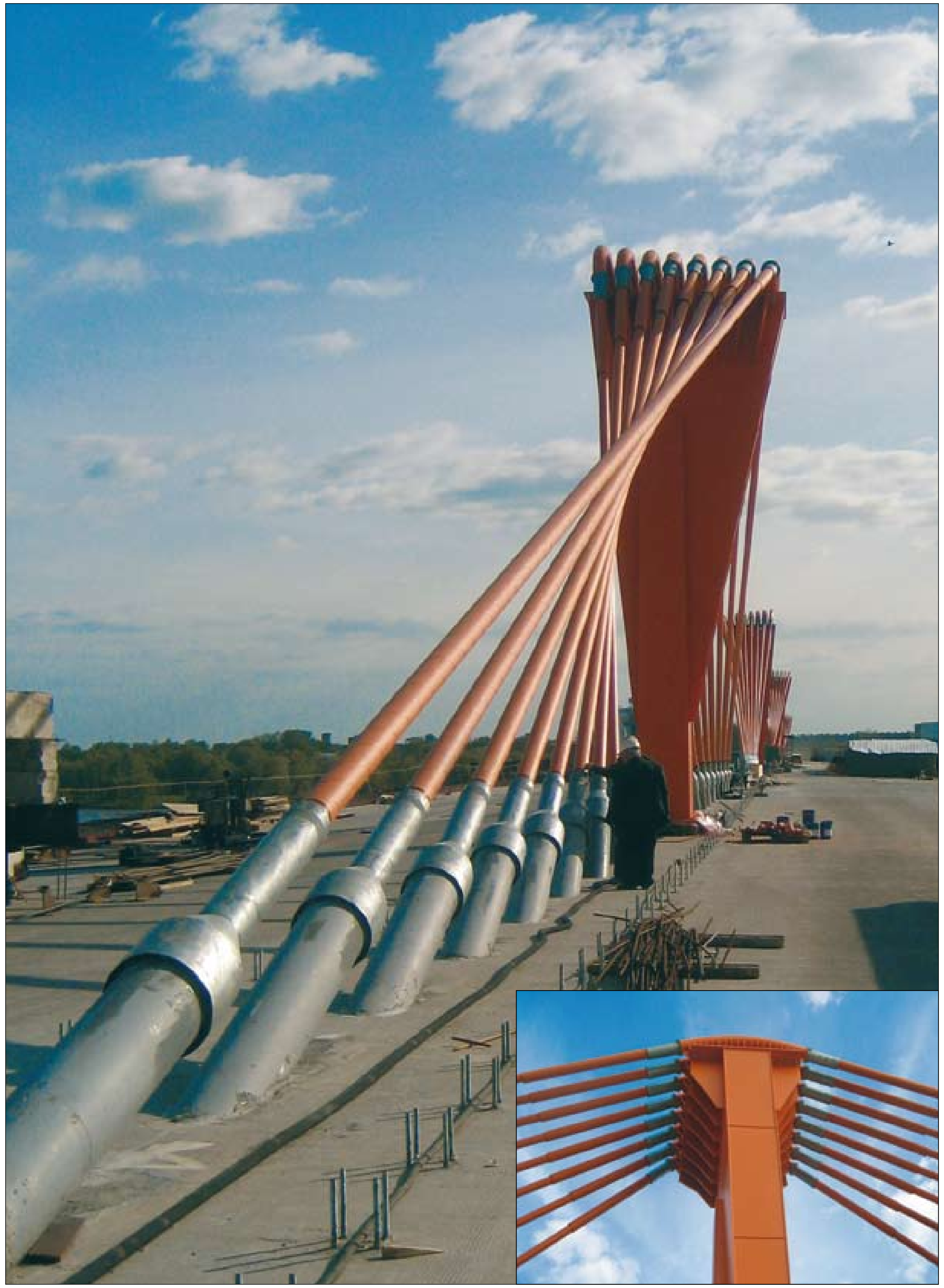
The development of the bridge architecture and design was entrusted to the design group Arhitektonika (Chief Architect Ingurds Lagzdiņš).

The chief designer of the bridge blueprint design and of overhead roads over Krasta and Maskavas Streets (trestles above Krasta and Maskavas iela) was Tiltprojekts Ltd., Manager Georgijs Rusinovs.

Constructors
Joint stock company Dienvidu tilts, Manager Māris Kvite.

Construction Supervisors
Unlimited: L4&PVAB partnership. Bridge construction monitoring – Andrejs Brieže; trestle construction monitoring – Ivars Kalniņš.

Facts and Figures
- Bridge construction – prestressed reinforced concrete
- Total length of the bridge – 803 metres
- Width of the bridge – 34 metres
- Number of traffic lanes – three in each direction; bicycle path; pedestrian path
- Trestle construction – prestressed reinforced concrete
- Length of the trestles – 1,896 metres
- Number of traffic lanes – varies, from one to three
- Total length of the road – 2.1 km
- Expenses on realisation of the road (bridge and trestles) – LVL 135 million.



Lithuania

TUNNELS

- **Paneriai Railway Tunnel**
- Vilnius
- 1862
- Length of the tunnel 420 m

Photographer: Ona Stasiukaitienė

Built in 1982 in Vilnius when Russia started to extend the St Petersburg – Warsaw railway, which was 1300 km long. It is thought to have been designed by the Lithuanian engineer Stasys Kerbedis. The construction works were supervised by G. Perotas. This was the first 420 m long tunnel construction, not only in Lithuania but also in czarist Russia. At present it is disused. Another longer tunnel was built in Kaunas – at 1248 m long, it is still being used.

BRIDGES

- **Bridge Spanning King Vilhelm's Canal**
- Jokšų village, Klaipėda
- 1873
- Drawbridge

Photographer: Ona Stasiukaitienė

Built in 1873 over the King Vilhelm Canal. There were 10 bridges built over the canal, but only three remain. They were well adapted to navigation – in the middle of the bridge, under the cover, there is a gap for ship masts to pass through. The canal joined the Minija River at Lankupiai, in the Silute region, to the Curonian Lagoon at Klaipeda. The canal was used for trade, transportation, timber processing, watermills and peat production. With the canal, the polder system was introduced and agriculture developed.

Lithuania

BRIDGES

- **Bernardine Bridge over the Vilnia**
- Vilnius, over Vilnia River
- 1880
- Built by architect Levikis

Photographer: Gražina Lygnugarienė

Built in 1880 in Vilnius. The construction history goes as far as back as the 16th-17th centuries. Originally, it was wooden and was rebuilt several times. At the end of the 19th century, according to the project of the architect Levikis, a metal bridge was built. The length of the bridge is 18.07 m, with a width of 8.4 m. The railings and retaining walls of the bridge are elaborately ornamented, and the supports made of ashlar masonry. The bridge got its name from the nearby Bernardine church and monastery. The bridge is still being used and reveals the technical skills of the builders of those times, and is clearly part of the country's cultural heritage.

BRIDGES

- **Revolving "Chain" Bridge**
- Klaipėda
- Second half of the 19th century
- Still operating

Photographer: Ona Stasiukaitienė

Built in the second half of the 19th century in Klaipeda over the canal joining the river Dane with the castle fosse. It was the time when on the southern cape and along it, the lagoon industry was being developed and the canal, through which the boats and timber reached the castle moats, became an obstacle. There was a necessity for the bridge to be built. The original bridge was wooden then it was portal and later metal. It operates nowadays. Its length is 21.5 m, and width – 4.37 m. The quay was built in 1928 under the supervision of engineer Janas Simoliunas. That is an especially valuable and unique in the Baltic States forged- iron bridge with a manual control revolving mechanism and original girder system.

Lithuania

BUILDINGS

- **Vilnius Thermo - Power Plant**
- Vilnius
- 1903
- Today a museum

This thermo-power plant was built in 1903 in Vilnius. The construction works started in 1901; in 1902 there were two steam boilers, two steam machines, two 250KW power and 440V constant voltage current generators. In 1912 the first steam turbine in Lithuania started to operate. It generated electricity up to 1982. The exterior of the power plant is decorated with the sculpture 'Electra'. In 2003 the Museum of Energetics was set up in the building, where the old machinery is displayed. A Museum of Technology is being established there, too.

Photographer: Ona Stasiukaitienė

BUILDINGS

- **Uostadvaris Water Lifting Station**
- Šilutė region
- 1907
- Historical bulding

Photographer: Ona Stasiukaitienė

In 1907 the first polder and first pump-house on the canal of the Vilkine River were built in the Silute region, and drainage of 1952 hectares of meadow started. This was the only building of this sort in Lithuania. During the tide, water was pumped towards the side of the Nemunas. The place was named Uostadvaris, which means 'harbour estate'. The water lifting station has not lost its significance, even nowadays. However, the old machinery, made in 1906 (the pump with a transmission turbine, the Zeilich steam engine, the transmission with a flywheel weighing 4 tons), is kept in the Polder Museum as an exhibit. This is a valuable regional specimen of historical and architectural significance showing the construction technology of those days.

Lithuania

Photographer: Gintaras Česonis
Archive of department of cultural heritage

BUILDINGS

- **Kaunas Forths**
- Kaunas
- 1902 - 1913
- Today a museum

At the end of the 19th century, Russia, concerned about the protection of its western borders, prepared a fortification programme involving the creation of a system of bastions. In 1879 the emperor of Russia, Alexander II, signed a decree to build the Kaunas bastion. The construction of forts, barracks and military boroughs continued from 1881 up to World War I. On the eve of World War I, the city of Kaunas was surrounded by nine forts, other fortifications and batteries. The forts that remained are used for present-day purposes. For example, the ninth fort, with its fully remaining barracks and cannons, ammunition, sanitary and domestic rooms, food storerooms and subterranean passages is open to the public, as in 1958 a museum was established there which is still open today. The Kaunas bastion is significant in historical, urban and architectural aspects. Parts of the fortifications scattered around the city had an impact on the urban development of Kaunas.

Lithuania

BUILDINGS

- **Salakas Church of the Blessed Virgin Mary, Comfort of the Sorrowful**
- Zarasai region
- 1911

Photographer: Algirdas Vapsys

Built in 1911 in Zarasai region by the concern of the parish priest A. Kryzanauskas. This magnificent 78 m high church was built by the residents of Salakas from the donations of the parishioners. The untraditional building replicates the forms of the medieval times and is rare and interesting in the technological aspect. The unusually thick walls of the building are made using the ancient shell technique – the outer walls are made of huge ashlars, the inner ones – out of bricks. The gap between them is filled with smaller stones. In 1915, the church was consecrated as the Church of the Blessed Virgin Mary, Comfort of the Sorrowful. Without changing much and having been restored in 2008, the shrine witnesses the history of the Lithuanian national revival and reflects the professional skills of its builders. It is a significant monument of the cultural heritage.

BUILDINGS

- **Klaipeda P. Lindenau Shipyard with Boathouse and Under Crane Bridge**
- Šilutė region
- 1919

Photographer: Ona Stasiukaitienė

The shipyards in this area were in use as early as the middle of the 19th century. The shipyard, built in 1919, was run by the main constructor and owner, the engineer Paulius Lindenau. In 1922 the first sea steamboat, Cattaro, was made there. In 1944 the shipyard was evacuated, however the bridge assembled in 1923-1924 remained. In 1942 a hull and pipe workshop, a forge and a boat and yacht workshop were built. An unfinished boathouse with a slipway is still there.

Lithuania

RAILWAYS

- **Narrow - gauge Railway**
- 1920 - 1938
- Built during Lithuania's independence

Photographer: J. Junevicius
Archive of the Centre for the Lithuanian Cultural Heritage

This is a unique and significant technology monument in Lithuania, the only remaining specimen of transport technology witnessing the progress at the turn of the 20th century. This is the longest existing narrow-gauge railway in Europe (179 km). The different stages of its construction reflect historical events and economic development. In 1895 the first Russian private enterprise, established with the permission of the czar (since at that time Lithuania belonged to Russia), built the first section of the railway called Svencioneliai-Pastovai, which was 750 mm wide and 71 km long. During 1920-1938, when Lithuania became independent, new railway sections, bridges, depots and stations were built. The narrow-gauge railway established itself as a reliable means of transport. This railway is included in the register of cultural heritage of Lithuania and was proclaimed a cultural monument.

BUILDINGS

- **Vilnius Concert and Sports Palace**
- Vilnius
- 1973
- Award for architecture

Photographer: L. Budrytė
Archive of department of cultural heritage

Built in 1971 by architects E. Chlomauskas, J. Kriukelis and Z. Kamarauskas, and engineers H. Karvelis, A. Katilius, A. Kamarauskas and S. Kovarskaja, the project designers received a national award in 1973. The exterior details of the facades contain some features in the Brutalist style, and the roof uses stay construction. The palace contains some valuable interior constructions and architectural details, as well as décor. The building witnessed many historical events: in 1988 the Reform Movement of Lithuania had its constituent assembly here, and in 1999 Lithuania bid farewell to the victims of the struggle for independence who were killed at the TV tower.

Malta

RESTORATION

- **Wignacourt Aqueducts**
- Valletta
- 1610-1615
- Restoration in 1999

Written by: Perit Chanelle Muscat

Historical outline

The new capital, Valletta, was under construction but it lacked a source of water. The natural spring in Valletta, discovered in the 1560s, another spring in Marsa and the collection of rain water from the roofs of the newly built cisterns excavated in natural rock soon proved to be insufficient for the needs of the growing population.

In 1596, a Jesuit, Padre Giacomo, was brought in to advise on this matter. The idea was to bring water from the northwest area to Valletta, where it was desperately needed. His proposals were immediately accepted, and financial commitments from various private and public sources were soon obtained. Work was immediately started, but soon suspended, as it had become clear that the final cost was going to be much higher that the first estimate provided by Padre Giacomo.

The aqueducts were finally constructed starting in 1610 under the advice of another Jesuit, Father Natale Tomassucci, and completed in 1615 during the rule of Grand Master Alof de Wignacourt (1601-22). Work during the last three years was carried out under the direction and supervision of Bontadino Bontadin, an expert on such matters from Bologna, assisted by Giovanni Attard, amongst others, a local 'capomastro' who had indicated how the aqueduct could be constructed across certain depressions on the ground. In order to provide a sufficient supply, several springs were joined by subterranean conduits and their waters made to flow into a single channel. The chief spring rose at a place called Diar Chandul, about two miles west of Mdina, the old capital city. The aqueduct runs underground as far as Attard and afterwards it alternately rises and falls with the unevenness of the ground until it reaches the city. However, Santa Venera is situated on higher ground than Valletta, and this presented a major problem for water to reach the city by gravity. Based on the technology available at the time, the only feasible solution was the construction of a series of arches so that a gradual gradient could be maintained.

Grand Master Wignacourt paid for the whole 9-mile line of aqueducts. A generous portion of the arches in Santa Venera still cling to a tower that was constructed to monitor the flow of the water. Stone arches survive all the way to Fleur de Lys Junction, where a marble tablet on an elaborate archway once declared, 'Hitherto Valletta has been dead. Now the spirit of water revives her.'

Restoration of the monument

In 1999 the Local Councils through which territories the aqueducts pass, together with other institutions and other private companies and consultants, formed a committee to safeguard, restore and upgrade this national monument.

The Wignacourt Aqueducts are made up of 361 arches which cover a length of 9 miles and were in a terrible state of repair. They stretch from Attard to Hamrun, passing through a number of towns and along high-traffic main roads, which caused much of the deterioration. All along the 9-mile stretch, over the years many service providers had used the aqueducts as supports for their cables and posts. These have also proved very damaging to the aqueducts, both visually and structurally.

In most areas the surface damage was limited to biological soiling and thin layers of atmospheric pollution. In other areas, however, the exhaust fumes from the cars which are routinely parked under the arches had formed a thick tenacious black crust. Further investigation revealed that the stone under this black crust had deteriorated badly.

In some places the vousoirs were so deteriorated that collapse of these arches was imminent. In some cases the foot of the pilasters had been constructed from the old water channels, their middle carved out to form a cylindrical hole. These stones were meant to be joined together and used as 'pipe work' in the first attempt to construct the water transport system. However, due to the fact that the land was elevated at Santa Venera, the pipe work idea had to be discarded, as the water could not be made to travel solely by gravity, and so a structure had to be created to cater for the dip in ground level. When the aqueduct concept started to form, these stones which had already been carved were not wasted but used (standing upright, and therefore the cylindrical hole is completely concealed) at the foot of the pilasters. This means that the load-bearing area of the large stones is limited to about 4 inches around the perimeter of the stone. In some areas this had been reduced to only an inch or even completely eliminated. Such arches were also in danger of collapse. Close to the Fleur De Lys roundabout, the arches are built on very soft rock, which is crumbling, endangering the overlying construction.

The restoration works were carried out in two phases: as an initial step, the first phase consisted of a photogrammetric survey of the monument in order to have documentary evidence of the structure before the actual restoration could commence.

The restoration project eliminated the danger of collapse and consolidated the structure, as well as removing as much soiling matter as possible to prevent further deterioration. Only the stones that were a potential danger to the structure itself and to passers-by were removed and replaced with new stones. Each replaced stone was the same in size and configuration as the one which had been removed.

Other treatments included the removal of metal inserts by using a corer to prevent splitting of the masonry blocks, removal of biological growth by cleaning algae and lichens from the stone surface using an appropriate biocide, removal of weeds with weed killer to prevent damage to the stone when pulling out the plants and removal of oleander plants in the close vicinity of the monument, as the root system of these plants is very damaging.

Cleaning of the soft stone fabric was carried out, starting with the simplest and softest methods, such as dry brushing and water.

The joints between the stone work were cleaned and any loose mortar was removed, while the mortar which was still in good condition was retained. A mortar similar to the one on the monument was then be used to point the joints. The mortar consisted solely of hydraulic lime, sand and stone dust. Clay particles were added to the mix to bring the mix closer to that already existing.

The second phase of the restoration consisted in embellishment work to the monument. The Wignacourt Aqueduct once ran through miles of countryside, and the arches stood out proudly as a great engineering feat which gave life to the city. Today an urban jungle has sprawled around the monument, which shrinks the majesty of the arches to nothing more than part of a derelict background.

The embellishment project provided a visual separation from the urban context in which the aqueducts are now found, and provided a pedestrian walkway in the villages which it traverses. This served to create a psychological sense of belonging for the residents who adopted the stretch as their promenade. As part of this project, service providers that up till then had used the monument as a support for their cables and poles were instructed to remove them and use other, more appropriate, systems.

The whole aqueduct, or rather that part which still remains, now stands out again in its full glory.

Malta

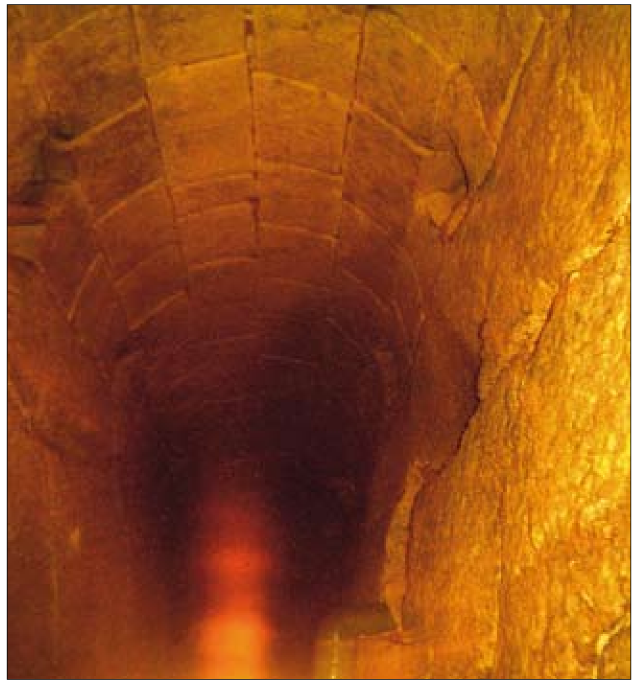
INFRASTRUCTURE

- **Valletta Sewerage System**
- Valletta
- Construction started in medieval times (16 th century) by Knights of St. John
- Upgraded in the early 19 th century

Written by: Perit Edward Said

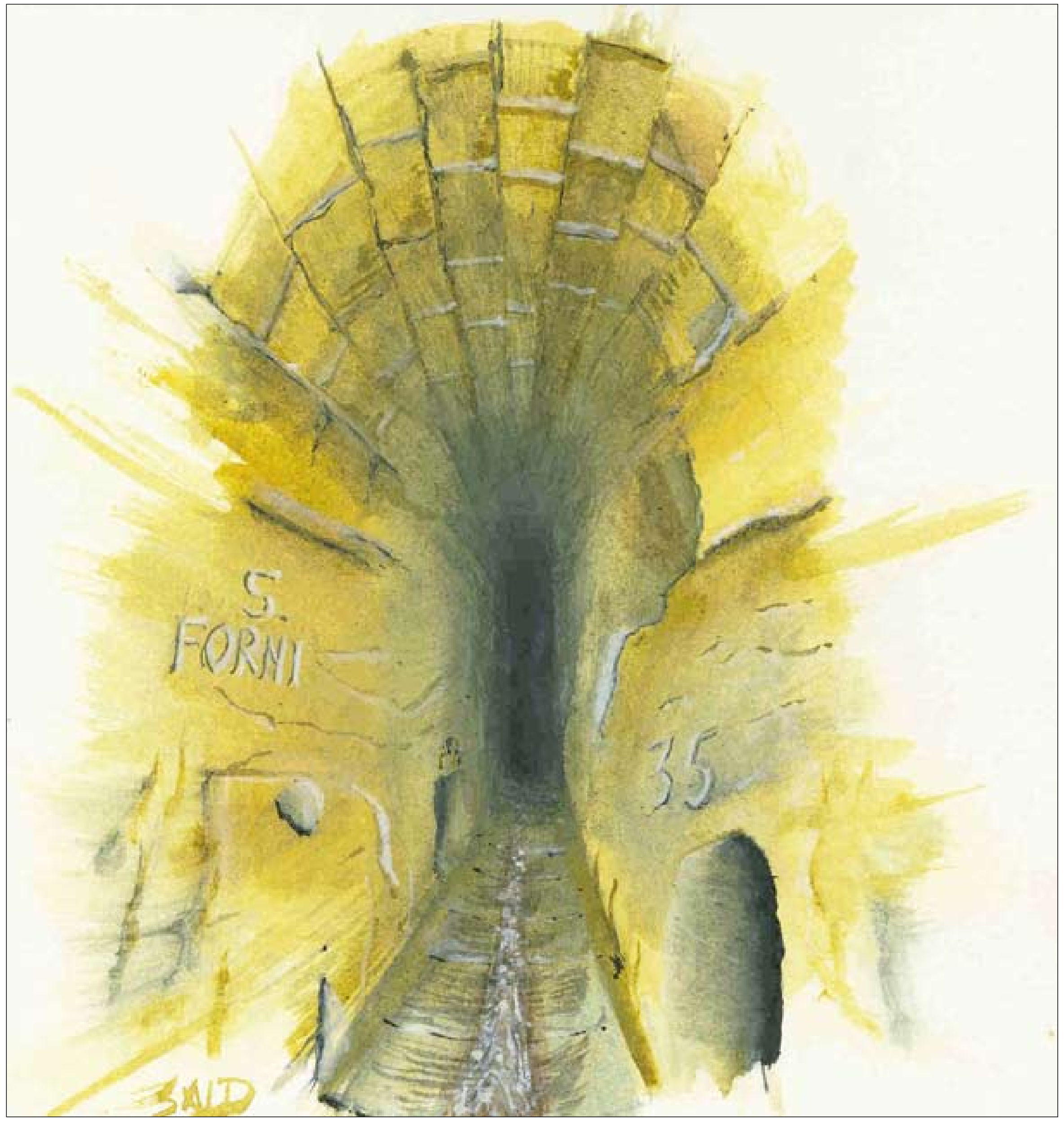
Valletta is reputed to have an extensive subterranean dimension. Rock-cut water channel networks, cisterns, public granaries, covert military tunnels, air-raid shelters and, last but definitely not least, sewerage networks. Of all the spaces beneath the city it is these last ones that are if not the most interesting, then the most unique in the entire country. The sewerage system of Valletta dates back to the earliest days of construction, most likely even before the streets were constructed. By studying the sewerage system, it is clear that the Knights of St. John not only wanted an avant-garde fortified city but also a clean one. With a history of plague still much in living memory, they constructed a hierarchy of trenches and passages, all carefully connected, channelling the effluent of every building down to the sea. Water was a known scarcity and the engineers devised the gravity-operated sewers with sufficient inverts to channel off the effluent without flushing. Furthermore, the sewer trajectories were strategically set at safe distances from any water cisterns and public reservoirs. Each edifice in the city had to have a specially designed cesspit and access point into the public sewers, as strictly stipulated in two of the Officio delle Case (Urban Planning Authority of the day) laws.

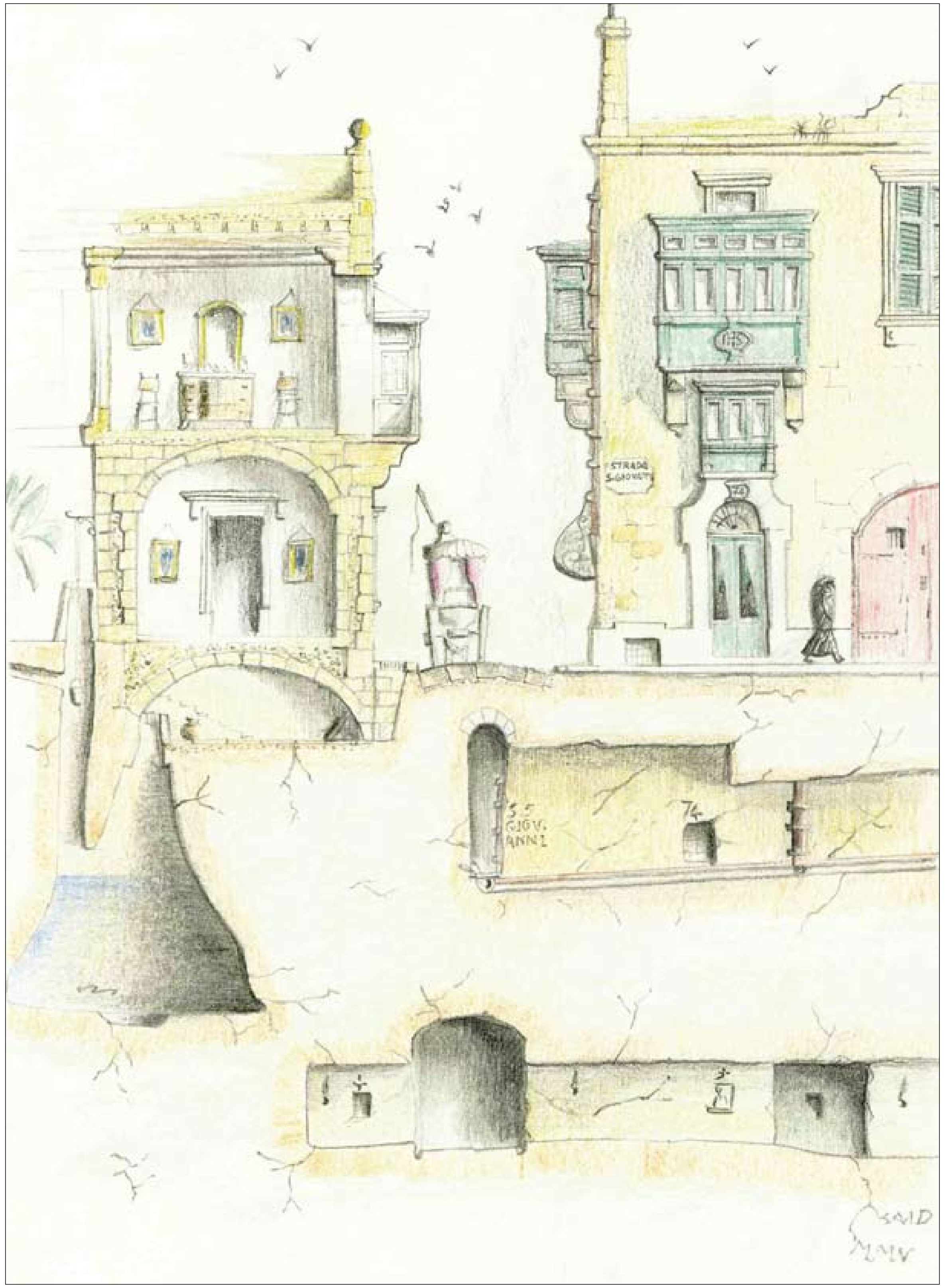
With the coming of the British in the early 19th century and after Malta's worst plague outbreak ever recorded in 1813, the authorities set out to radically upgrade the system, only doing so after arduous disputes in the latter half of the same century when a closed system was introduced, complete with trapped house connections, adequate ventilation, and invested in a deep low-level intercepting sewer girdling the perimeter of Valletta, thus putting an end to the numerous coastline sewage outflows. Each sewer had the overlying street name engraved at intersections as well as the door numbers of the buildings above in a bid to alleviate the already gruelling tasks of sewer workers. The British authorities, together with the Public Works department, also meticulously surveyed the upgraded system and drew up numerous master plans, sections and details, most of which can presently be found in government archives and are of immense historical and artistic significance.



The Second World War transformed subterranean Valletta almost beyond recognition. The city's undercroft was mined into a veritable labyrinth, connecting any existing spaces, whether crypt, cistern, basement or tunnel, in order to shelter the thousands living in and commuting to the city. With bombs raining down, the architects, civil engineers and masons employed in designing and creating the passages took great care not to touch the drainage system, furthermore ensuring that the level of refuges was always at a safe distance from the sewers.

The post-war years saw the sad neglect of the aging sewerage network. A visit inside the subways today clearly reveals their deteriorated condition, which is being accelerated by uncontrolled connections and careless, make-do interventions. The use of the subways for the accommodation of telephony cables has at least ensured that the system is monitored. The fact that the sewers are still very much in use today is a testament to their importance, indeed an integral part of the city's life-line. People must, however, realise that, unlike most of the rest of underground Valletta, these are a unique monument in civil engineering that warrants further research and the utmost protection and preservation.





Malta

HARBOURS

- **Grand Harbour Breakwater**
- Valletta
- 1902 - 1909
- Largest civil engineering work ever tackled in Malta till that time
- 114,500 m^3 of precast concrete blocks were used for the breakwater

Written by: Perit William Soler

The Grand Harbour in Malta has long been coveted by the major European maritime powers over the centuries. Malta's position in the centre of the Mediterranean and its fine harbours provided a secure base for the British Navy during the nineteenth century.

At the turn of the twentieth century, the British authorities fully appreciated the harbour's value as a safe naval base, and they sought to protect the Grand Harbour's mouth as a defence against bad weather and a potential naval attack by enemy forces.

In February 1900, the renowned firm of civil engineers, Coode Son and Matthews of London, were commissioned by the Admiralty to draw up a scheme to protect the Grand Harbour from both of these two diverse modes of attack. The proposals incorporated four basic features: the 1240 ft (378 m)-long St. Elmo Arm along Monarch's Shoal in a slightly curved line, the 400 ft (122 m)-long Ricasoli Arm in the north-by-northwest direction, a spur pier (which was never built) at the base of L-Imgerbeb Point, and the levelling down of the rocky foreshore under the bastions to form a wave trap.

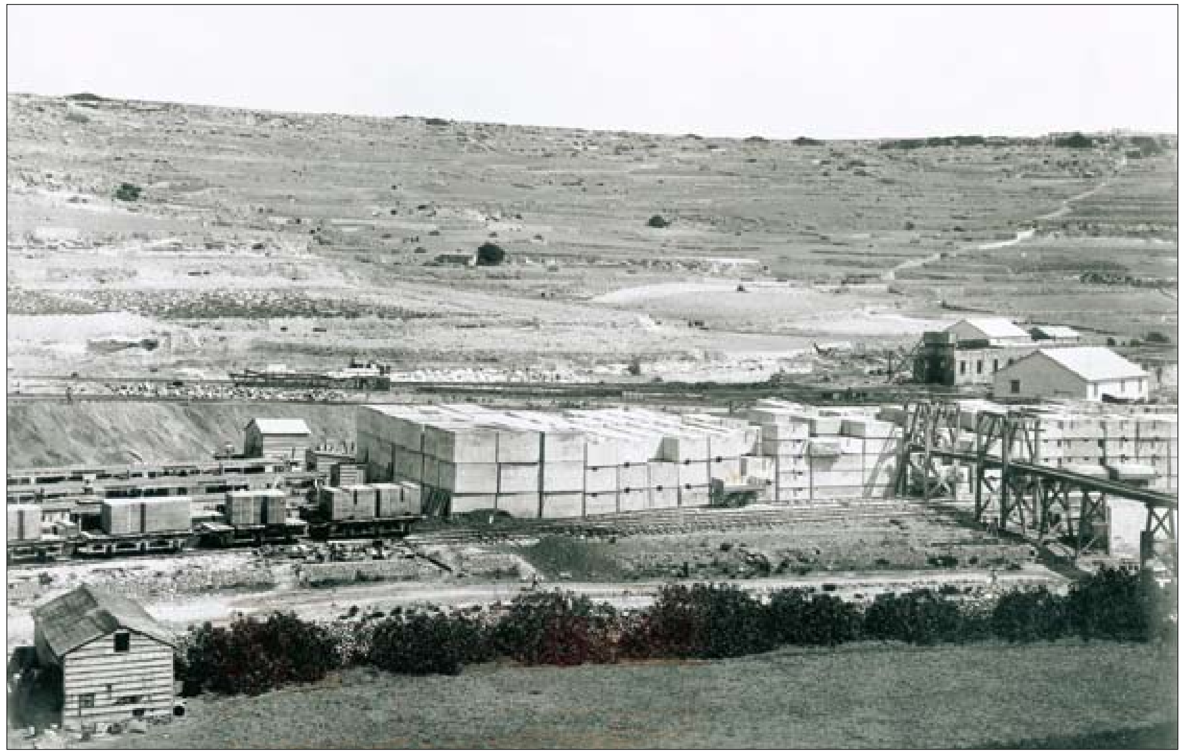
The design resulted in a winding steaming course and a boom defence as protection against naval attack, an increased anchorage area for naval vessels and a massive defensive wall against the most powerful northeast 'gregale' storms.

The British contracting firm, Messrs S. Pearson & Son Ltd, was awarded the contract to build the breakwater according to these designs, and works started in earnest on the Ricasoli Arm in late 1902. This project was the largest civil engineering work ever tackled in Malta up till that time, surpassing in scale even the naval dockyards.

The breakwater arms consist of precast concrete blocks bonded to each other to form an almost vertical gravity barrier wall, 37'5" (11.4 m) thick and a maximum of 46' (14 m) deep, to resist the most powerful waves, and the layout of the arms was designed to allow for a system of floating steel boom defence with anchorage chambers hidden in the St. Elmo breakwater arm and the tip of the Ricasoli Arm.

A precast block yard was built in Mistra Bay in the north of the island, where concrete blocks weighing between 25 to 42 tons were cast on a factory bed, which historically became the earliest precast yard in Malta on a large scale. The quarry in Mistra Bay was chosen because of the existence of hardstone, a type of coralline limestone which was the best quality to be found on the island. Pearson also opened three quarries in Gozo at ir-Ramla il-Hamra, Ghar Dorf North of Ras il-Qala and Hondoq ir-Rummien. The latter two quarries were opened specifically for docks 4 and 5 by Pearson in 1901. The stone was used to supplement the Mistra Quarry and for the cladding of the breakwater section above water level, as upper coralline Gozo limestone is the hardest available in the Maltese archipelago and has extremely good long-term weathering and durability properties. The masonry work on the breakwater is a showpiece of Maltese stereotomy in hardstone, especially evident in the curved heads and in the lighthouses, although Pearson could have used imported stone from Sardinia, Trani and Switzerland, as the contractor did in the floors of Docks 4 and 5.

The interlocking blocks were transported to the site by sea on barges and lowered into place through the use of Goliath cranes on staging, guided by divers in a primitive diving bell. The jointing method of the blocks adopted was to have two vertical precast concrete dowels in each joint of every block, and horizontal dowels were also introduced to resist horizontal movement in relation to each other. In this way, the construction resulted in a homogeneous monolithic barrier wall which could also resist overturning and sliding.

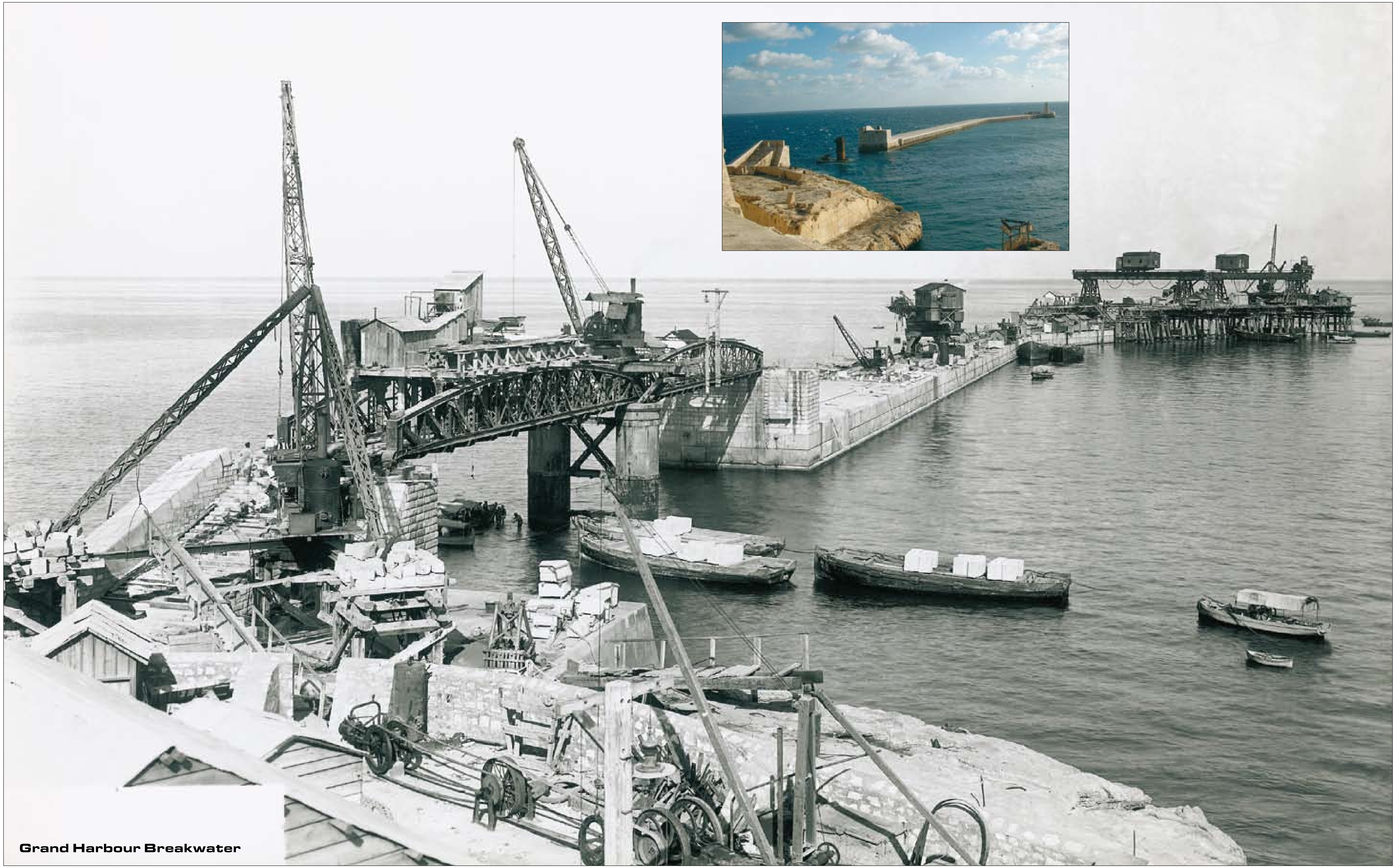


The construction works suffered serious setbacks in 1904 when a gregale storm destroyed the staging and two Goliath cranes on the Ricasoli Arm in February and the loss of another Goliath crane on the St. Elmo Arm in November of the same year. New staging and Goliath cranes were erected, and steady progress was made in both arms between October 1906 and October 1908. The Admiralty certified the contract complete in September 1909, seven years after the start of works on shore. The breakwater arms eventually consumed 150,000 cu. yds (114,500 m^3) of concrete, the greater part of which was placed by divers. The completed works at the end of the contract cost about one million pounds. The contract value was 467,327 pounds.

The construction system, the wall-type breakwater, was used in Dover Harbour by Pearson, but the sheer size of the blocks was no guarantee against damage, as happened in Bizerta during the same storm that damaged the Malta breakwater, where cyclopean blocks weighing 5000 tons each (102 ft x 26 ft x 26 ft; 31.1 m x 7.93 m x 7.93 m) could not resist the power of the sea.

The Grand Harbour breakwater has not suffered any significant damage from the heavy storms that destroyed other breakwaters in the Mediterranean. Failures of wall-type breakwaters in Catania, Algiers and Genova eventually led to the mound-type of breakwater design at Casablanca, Augusta, Crotone and the reconstructed Catania breakwater. The Malta breakwater is one of the few successful wall-type examples of breakwater construction in the Mediterranean of the early 20th century, which has vindicated the vertical wall barrier theory, albeit in technically shallow waters.

The only design criterion of the entire breakwater scheme, which has today become anachronistic, is the winding steaming course, which was a naval requirement aimed at making a naval attack by enemy ships as difficult as possible. Today this winding steaming course has become a serious handicap for supertankers and large cruise ships of the 21st century, necessitating the use of powerful tugboats to prevent them from running aground. One must not forget that a century ago, the dreadnought was the naval architect's yardstick, as aircraft carriers were not yet on the horizon, let alone bulk carriers, supertankers and mega cruise ships.



Grand Harbour Breakwater

Portugal

BUILDINGS

- **Downtown**
- Lisbon
- 1755
- Reconstruction after a large earthquake

On 1 November 1755, a large earthquake struck Lisbon. The city was reduced to rubble by the two major shocks of this great earthquake and the waves of the subsequent catastrophic tsunami. A huge fire completed the destruction of the city.

Six major plans were drawn up for the reconstruction of downtown Lisbon, led by Manuel da Maia. The chosen plan, from Eugénio dos Santos, was the most rational and innovative, developing the concept of an integrated plan with a global policy for the city and related infrastructure, architecture, urban design and economic processes. Based on a rectangular arrangement of longitudinal and transverse streets, the buildings were drawn up by Casa do Risco das Obras Públicas with a uniform composition and height as one of the most eloquent urban developments of the Enlightenment period.

Prof.ª Ana Tostões

Portugal

BRIDGES

- **Bridge Maria Pia** (Ponte Maria Pia)
- Porto, Douro River
- 1877
- Built by Gustave Eiffel
- Main span 160 m, a world record at that time

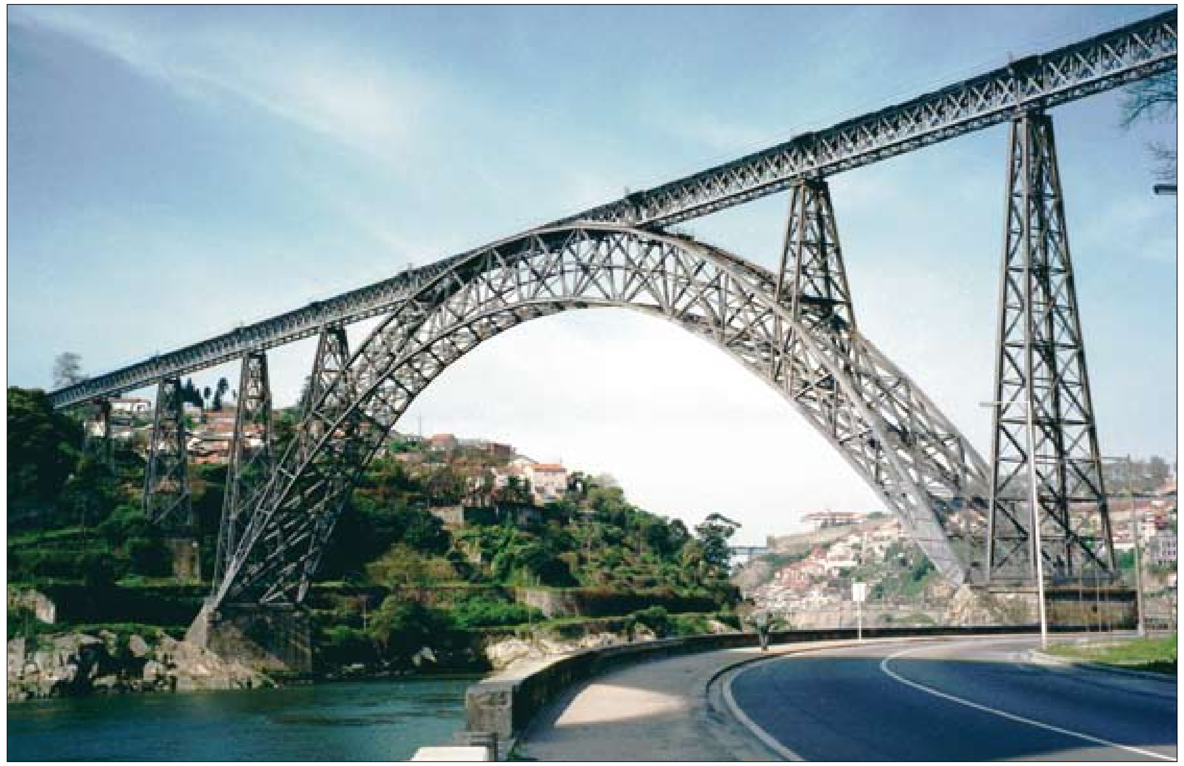
In 1856 railway construction began in Portugal connecting Lisbon to Madrid, which was completed in 1863, followed by the connection Lisbon to Gaia (south of Porto) in 1864. These main tracks were followed by several other connections to southern, central and northern Portugal.

Due to major river crossings in central and northern Portugal, several important bridges were built in steel (and wrought iron) during this period. The most famous is the crossing of the Douro in Porto (Ponte Maria Pia), built by Eiffel in 1877, with a central span of 160 m, a world record at that time.

The main railway network was built essentially during the end of the nineteenth century, with a total length of around 2000 km, which has been in use to this day with many of the original steel bridges. For that period it represented an enormous achievement, one that facilitated transport and communication in Portugal.

Eng. J. Carrasquinho de Freitas

Photo: Robert Cortright, USA



Portugal

DAMS

- **Cahora Bassa Dam**
- Tete, Mozambique
- 1974
- Generating capacity 2075 MW
- Height of the dam 171 m

The Cahora Bassa Dam, one of three major dams on the Zambezi River system, is situated in Mozambique, in the province of Tete, and creates the second-largest artificial lake in southern Africa, with a flooded area of 2740 km^2, and a maximum length and width of approximately 292 km and 38 km, respectively. The total volume of the reservoir is 55,800 x 106 m^3. The Cahora Bassa Dam is a concrete double-arch dam, 171 m high, with a crest length of 303 m. The spillway, designed for a maximum discharge of 12,600 m^3/s, includes eight bottom orifices and an overflow sluice to divert floating debris situated in the middle of the dam. The power house, located in a cave on the right bank, is equipped with eight Francis units and has a generating capacity of 2075 MW, supplying power to Mozambique, South Africa and Zimbabwe. The system includes two converter stations, one at Songo, in Mozambique, and the other at Apollo, in South Africa. There are two parallel lines between these two stations covering 1400 km.

Prof. António Quintela e Prof. Antonio Pinheiro

Portugal

HARBOURS

- **Mitrena Lisnave Shipyard**
- Setúbal
- 1974
- An innovative free basin hydrolift docking

This is a major shipyard located in the Sado Estuary, some 50 km south of Lisbon. The shipyard has been in operation since 1974 and accommodates all types of vessels. More recently, a Hydrolift was built, extending the capacity of the yard. The entire infrastructure sits on an inland off the estuary edge which was gained by reclamation.

Main facilities in operation since 1974:

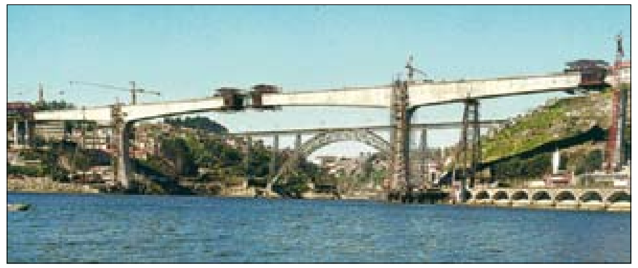
- Docking platform (420 m x 75 m)
- Drydock 21 (450 m x 75 m)
- Drydock 22 (350 m x 55 m)
- 4 jetties and 4 dolphins
- Quay-walls

Main facilities in operation since 2000:

- Hydrolift for vessels up to 80,000 dwt:
  - 1 entrance basin
  - 3 docking platforms.

Lisnave Shipyards SA

Portugal



BRIDGES

- **S. João Bridge**
- Porto, Douro River
- 1988
- Main span 250 m
  a world record for a railway bridge
  - free cantilever construction

The S. João Bridge is a railway bridge built in 1988 to supersede the centenary Maria Pia Bridge. The design was executed by Prof. Edgar Cardoso as a concrete structure with a continuous deck of a total length of 1030 m and a main structure over the Douro River with a span of 250 m. This span is still a world record today for a railway bridge built by the cantilever method with segments built in situ.

The deck has a double box section and the track has a ballast-less solution, with an innovative design to prevent derailments. The structure was fully instrumented during construction and is still monitored on line by the National Civil Engineering Laboratory (LNEC).

Prof. Fernando Branco

Photo: Robert Cortright, USA

Portugal

DAMS

- **Alto Lindoso Dam**
- Viana do Castelo
- 1993
- One of the largest subsoil power plants in Europe

This dam was built on the Lima River, in the north of the country, close to the Spanish border. It is a concrete double-arch dam, 110 m high, with a crest length of 297 m. The dam includes a spillway consisting of two controlled shafts with downstream flip buckets, located on the right bank, with a total capacity of 2760 m^3/s. The effective reservoir volume is 348 x106 m^3. The underground power plant, with a main cave of 21 x 42 x 9 m^3, at a depth of 340 m below the substation, is equipped with two Francis turbines with a unit capacity of 317 MW, the largest in Portugal, for a maximum turbined flow of 125 m^3/s, and outputs an annual average production of 948 GWh. This makes it one of the largest subsoil power plants in Europe. This project received the IVth International 'Puente de Alcântara' Award.

Prof. António Quintela e Prof. Antonio Pinheiro

Portugal

BRIDGES

- **Vasco da Gama Bridge**
- Lisbon
- 1998
- Longest bridge in Europe
- Main span 420 m

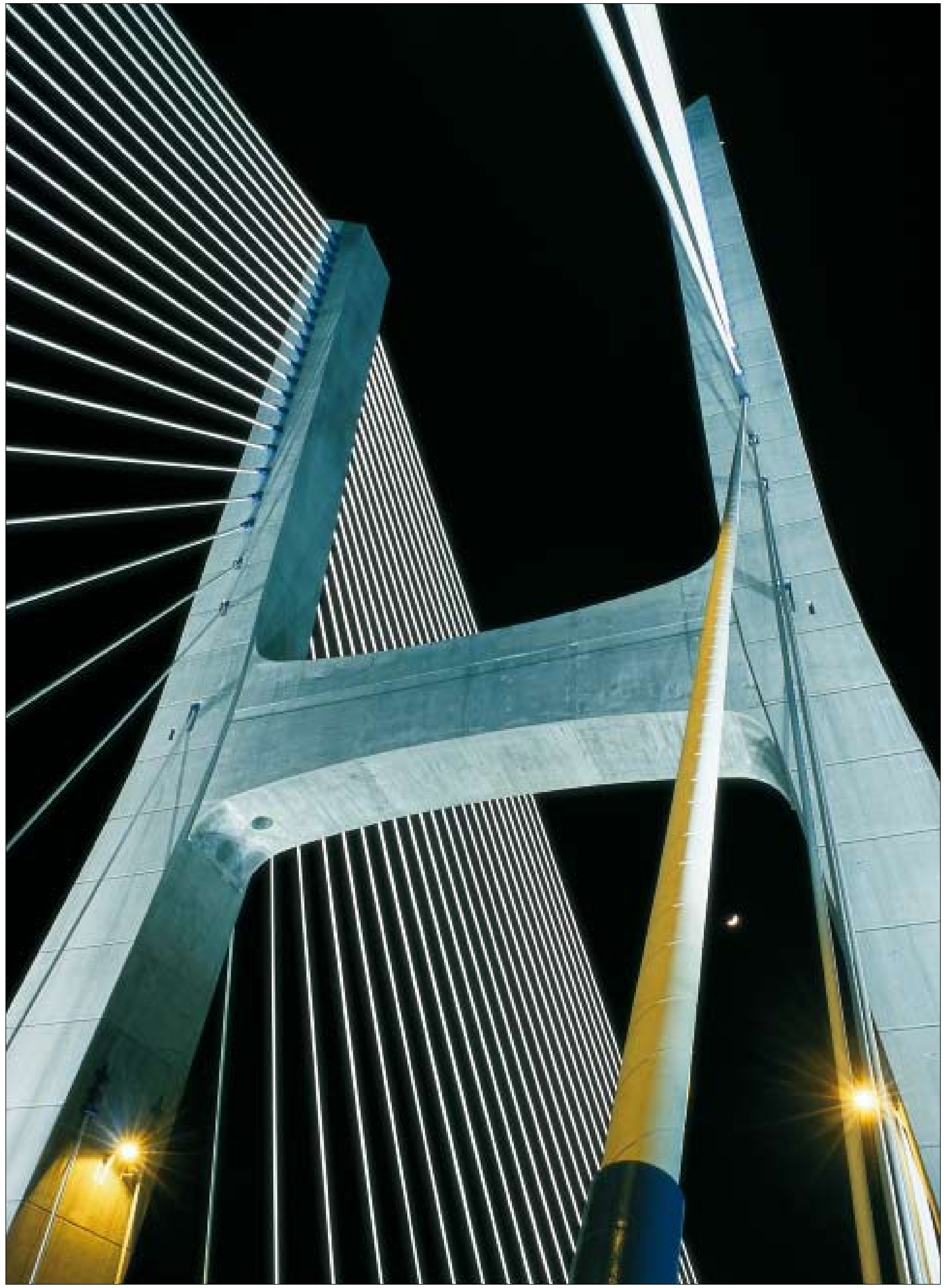
All photos: F. Vigouroux, courtesy of Freyssinet

The Vasco da Gama Bridge project consists of a 12.4 km crossing of the Tagus River in Lisbon, as such the longest bridge in Europe.

The crossing is composed of the North Viaduct, Expo Viaduct, Main Bridge, Central Viaduct and South Viaduct. The Main Bridge has a cable-stayed solution with a 420 m central span and three lateral spans on each side of 62 + 70.6 + 72 m. Foundations along the crossing include piles up to 85 m deep.

Innovative elasto-plastic dampers were placed between the deck and the towers to improve the bridge's seismic performance. Specially designed longitudinal drifts were implemented under the deck to achieve aerodynamic stability up to a 230 km/h wind speed. New cable technology was adopted to prevent traffic, wind and rain vibrations. The bridge was the first structure designed according to the Eurocodes for structural safety and durability associated with a service life of 120 years. This led to special control measures of material properties during construction and to permanent monitoring of the structure during its service life.

Prof. Fernando Branco



Vasco da Gama Bridge

Photo: courtesy of Freyssinet

Portugal

AIRPORTS

- **Madeira Airport Runway**
- Funchal, Madeira Island
- 2001
- One of the unique runways in the world

The Funchal Airport Extension, Madeira Island, Portugal, received the IABSE Outstanding Structure Award for being ‘a world-unique runway expansion project of supported concrete over sea-reclaimed land, sensitive to environmental and aesthetic considerations’.

The final runway has the length of 2800 m and is 57 m above sea level, with a structural bridge 1020 m long and 180 m wide. It was designed to carry the landing impact load of a Boeing 747. The reinforced concrete structure consists of large portal frames with circular columns and prestressed beams supporting a bidirectional prestressed slab.

Prof. Fernando Branco

Portugal

DAMS

- **Alqueva Dam**
- Alqueva
- 2002
- Created the largest artificial lake in Europe

Alqueva is a multipurpose project aimed at social and economic development of the Alentejo region in the southeast of Portugal. The Alqueva Dam, located on the Guadiana River, is the main infrastructural element of this multipurpose project, which irrigates about 110,000 ha and includes hydroelectricity production. It creates the largest artificial lake in Europe, with a total storage of 4150 x 106 m^3 and a reservoir area of 250 km^2. It is a concrete, double-curvature dam, 96 m high, with a crest length of 458 m. The flood discharge appurtenances comprise two controlled chute spillways and two large mid-height outlets, with a total discharge capacity of 6300 m^3/s. The Alqueva Power Station, located at the toe of the dam, is equipped with two reversible pump-turbine generator sets, with a unit power of 130 MW. The mean annual energy output is 269 GWh. Pedrógão Dam, 24 km downstream of the Alqueva Dam, creates a reservoir which enables reversible operation of the Alqueva pump-turbine units.

Prof. António Quintela and Prof. Antonio Pinheiro

Portugal

HARBOURS

- **Terminal XXI**
- Sines
- 2004
- 940 m of deep water quay
- Handling capacity of 1,320,000 TEU/year

Terminal XXI is located in Sines Harbour and has been operating since 2004 under a concession to PSA – Port of Singapore Authority.

The terminal has natural depths of 16 m. The quay is 380 m long and is equipped with Post-Panamax and Super Post-Panamax gantry cranes. Works are in progress to extend the quay to 730 m by 2009. The capacity of the terminal will then increase to 800,000 TEU/yr. At the conclusion of the project the length of the quay will be 940 m and the handling capacity 1,320,000 TEU/yr.

There are direct connections from the terminal to the national rail and road networks. The roads are integrated in Priority Axis 16 – Sines/Madrid/Paris of the Trans-European Transport Network. An ambitious plan is being implemented to further expand road and rail access, ensuring intermodality for connections within the country and to Spain, in particular to the Madrid area.

Main facilities:

- Quay length: 380 m (2009: 730 m)
- Depths of 16 m
- Handling capacity in 2008: 400,000 TEU (2009: 800,000 TEU)
- Container handling: Post-Panamax and Super Post-Panamax gantry cranes

Characteristics at the completion of the project:

- Quay length: 940 m
- Depths of 16 m
- Handling capacity: 1,320,000 TEU
- Container handling: 9 Post-Panamax and Super Post-Panamax gantry cranes

Prof. A. Pires Silva

Romania

BUILDINGS

- **Antim Monastery**
- Bucharest
- 1713
- The monastery houses the patriarchal chapel and episcopal residence

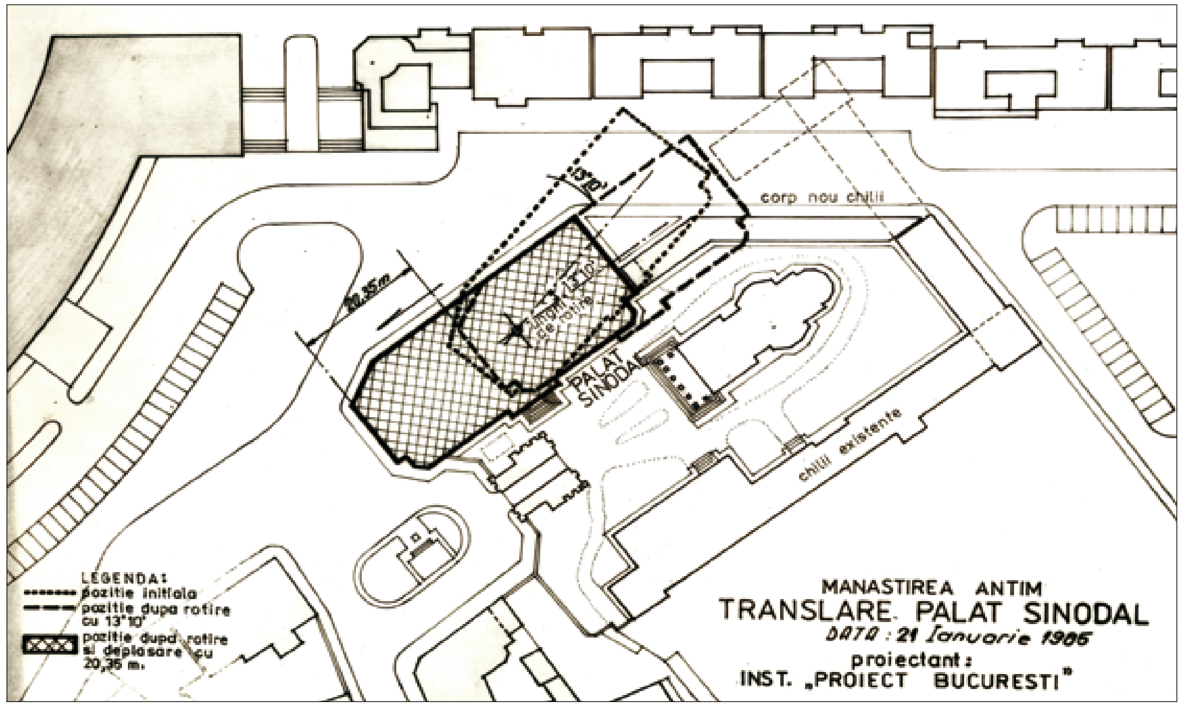
Photos taken, with the author's permission, from the book „Lucrări publice din vremea lui Carol I" by Nicolae Noica, 2008

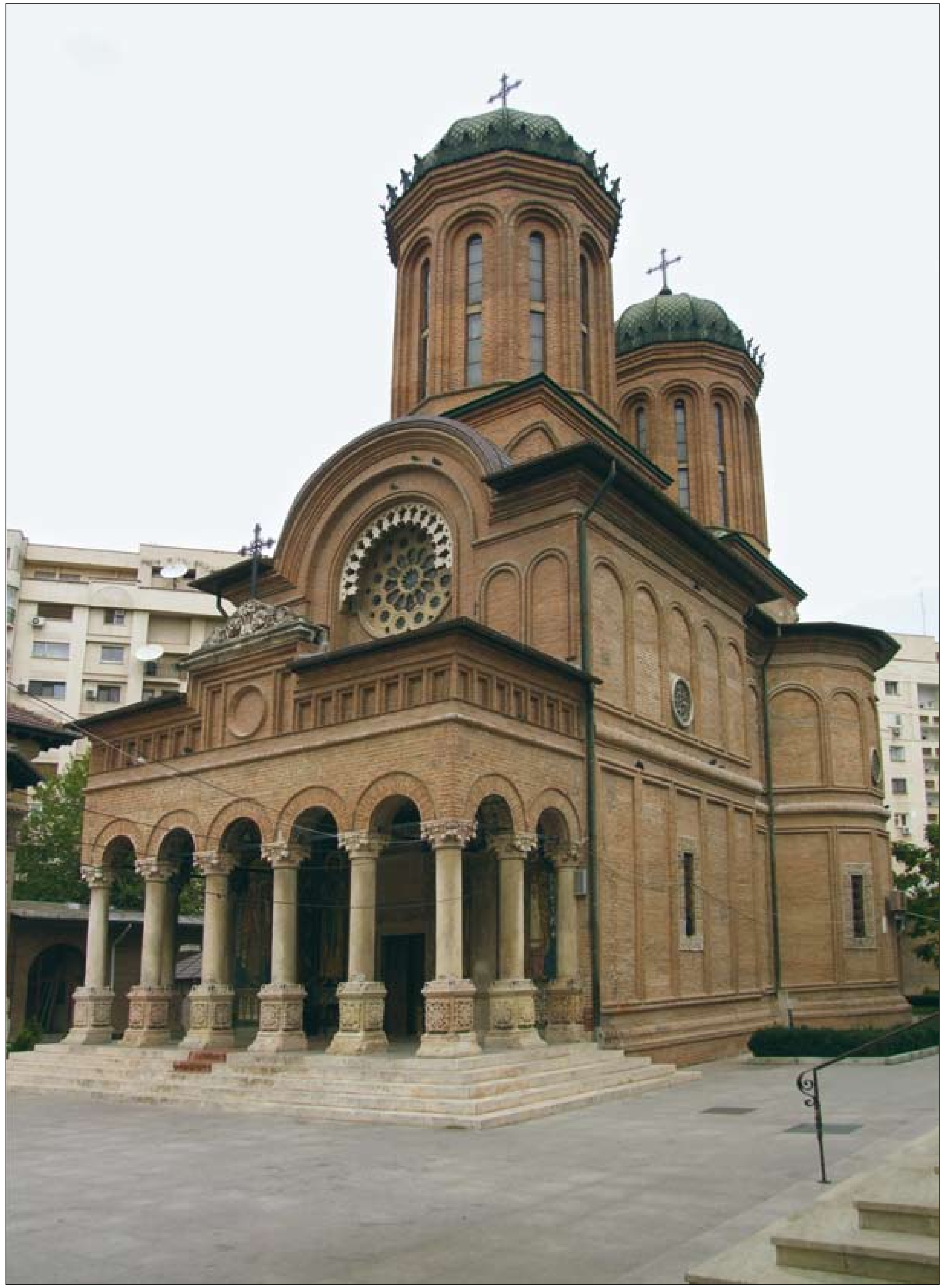
Built in 1713, the Antim Monastery, which currently houses the patriarchal chapel and episcopal residence, has been subject to several restoration works in 1746-1747, 1863 and 1950-1953. The last major integral restoration of the monastery complex took place in 1964-1966. Construction of the St. Sinod Palace started in 1910 and the St. Sinod Library was set up in 1912.

The church, built in the Romanian Brâncoveanu style with some Italian Baroque influence, is the only 18th century example of a trefoil-shaped plan. The church is 30 m long by 10 m wide. The 1863 restoration added the pulpit and the choir, carved from oak to the designs of Karl Storck. In 1984-1986 the entire St. Sinod building was relocated almost 20 m to the west, using a method for lifting and moving structures devised by Dr. Eng. Eugen Iordăchescu. The whole complex, including the church, monk's cells, chapel, steeple and abbot buildings, was designed by the Orthodox clergyman Antim Ivireanul, under his direct supervision of both architecture and murals.

Murals (restoration): Gheorghe Tătărăscu, Dimitrie D. Nicolaide, Costin Petrescu, Olga Greceanu
Lifting and movement engineering solution: Dr. Eng. Eugen Iordăchescu

Relocation of the church





Romania

RAILWAYS

- **Buzău - Marașesti Railway**
- Buzău County
- 1881
- All of the 77 bridges and footbridges were manufactured from timber

Locomotive and wagons dating from 1900

Photos taken, with the author's permission, from the book „Lucrări publice din vremea lui Carol I" by Nicolae Noica, 2008

The Buzău-Mărășești Railway (length 90.3 km) runs parallel with the Carpathian Arc and frequently along a contour line in the plain. Only the crossings of the Buzău River pose a challenge. All the 77 bridges and footbridges were manufactured from timber. The major bridges, of which there are eight, measure a total of 1325 m in length and have 10 and 15 m spans. Thus, the bridge over the Buzău, with a length of 360 m, has 24 spans of 15 m. The biggest fill along the route is in the Buzău alluvial plain, with a maximum height of 13.2 m, and the largest cutting is that on the right bank of the same river, where it has a maximum height of 9.8 m. The superstructure consists of rail type 32, in 6 m sections, made of steel delivered from the John Cockerill Company in Belgium. It was the second line in the country where this type of carbon steel rail was employed.

Contractor: Ion. G. Cantacuzino - the first Romanian specialised public works contractor
Design and execution of the line was led by engineer Dimitrie A. Frunză, the engineers' team and technicians consisting of engineer Grigore Demetrescu Tassian, C. A. Mironescu, L. Pancu and G. Stoenescu.

Railway station on the route Buzău - Mărășești line

Romania

BUILDINGS

- **Gheorghe Lazăr National College**
- Bucharest
- 1890
- Carrara marble was used for the stairs and floors

Photos taken, with the author's permission, from the book „Lucrări publice din vremea lui Carol I" by Nicolae Noica, 2008

The building, erected in brick masonry with hydraulic lime mortar and concrete foundations, was designed in an eclectic style, with a rational arrangement of decorative elements. The façades are structured in three parts: base, ground level and upper level. The frontage is articulated by openings created by vertically and horizontally oriented bays. The building's dynamic is achieved through the clock tower and the subtle play of volumes.

Natural stone was only employed for the main entrance frames, the stairs and the floors, for which Carrara marble was used. The ground floor is dominated by horizontal rustication and numerous rectangular openings. The ornamentation consists of pilasters and column capitals, plant motifs, ornamental blue enamelled brick and forged iron anchors, which are used structurally and decoratively. The main entrance is marked by a stone frame adorned with enamelled bricks.

From its inauguration the college was endowed with modern physics and chemistry. Gheorghe Lazar National College is also today an institution of general higher education.

Architect: F. Montaureanu
Furniture: Johan Schmidinger

Romania

BUILDINGS

- **Romanian Athenaeum**
- Bucharest
- 1886

Photos taken, with the author's permission, from the book „Lucrări publice din vremea lui Carol I" by Nicolae Noica, 2008

The Romanian Athenaeum was designed as a multi-purpose cultural venue. Since 1953 it has been the home of the George Enescu State Philharmonic Orchestra. The structure is a rigid steel frame with masonry infill, which has proven a good construction method in regions subject to seismic activity. The foundations are made of concrete with hydraulic lime; the floors over the basement and lobby are formed of steel joists with vaulted brick infill. The walls and columns are built from high-quality masonry with hydraulic lime or rich lime mortar, while perforated bricks were used for the stage wall.

The main entrance with its peristyle is identical in proportions to that of the Erechteion temple on the Acropolis. The eight columns, 12 m in height, support a large triangular pediment. Twelve cast iron columns clad in stucco imitating marble support the central dome of the lobby rotunda, above which the large conference hall is located. Four winding stairs lead directly to the concert hall, which is 28.5 m in diameter and 16 m in height. It has a suspended ceiling supported by the steel ties of the dome's steel structure. It consists of 20 radial mild steel ribs, a closing ring and connection rings. The central cupola is covered in zinc with an ornamental perch topped by a tripod, which is reminiscent of the Choragic Monument of Lysicrates in Athens. The ceiling in the large conference hall and museum were carved and decorated by various Italian and German artists. The overall height of the building is 41 m.

Architecture: Arch. Albert Galleron
Architectural supervision:
Arch. Constantin Băicoianu
General building contractor: Dobre Nicolau
Dome design and execution: Beuchelet
(Grünberg - Silesia)
Marble stair execution: Karl Storck
Murals: Costin Petrescu
Design and restoration (after WWII):
Eng. Emil Prager

Romania

BUILDINGS

- **National Bank of Romania (BNR)**
- Bucharest
- 1890

Photos taken, with the author's permission, from the book „Lucrări publice din vremea lui Carol I" by Nicolae Noica, 2008

The building was designed in the eclectic style of the end of the 19th century, with some neo-Classical elements. The Council Chamber is pompously decorated with floral and geometric forms in gilded stucco, endowed with Louis XIV-style furniture with Cordoba leather chairs, massive bronze chandeliers and purple brocade curtains with gold wire embroidery. The original space having become insufficient, remodelling took place: the floor area was increased by adding a level above the first floor of each of the four wings. The existing steel joist floor plate with vaulted brick infill was consolidated with a new reinforced concrete floor.

Architecture: Arch. Cassien Bernard & Albert Galleron
Site supervision: Arch. Eng. Nicolae Cerchez, assisted by Arch. Constantin Băicoianu
Execution: Romanian Society for Construction and Public Works

The design of the extension of the National Bank of Romania incorporated some of the latest measures against earthquakes in Europe when it was built. Erected in the period 1940-1950, this building ranks amongst the first constructions in the country designed taking into account the new anti-seismic standards introduced at that time.

Architecture: Arch. Radu Dudescu, Arch. Ion A. Davidescu
Structural Engineering: Eng. Ştefan Mavrodin, Eng. Tudor Constantinescu

National Bank of Romania (BNR)

Romania

Photos taken, with the author's permission, from the book „Lucrări publice din vremea lui Carol I" by Nicolae Noica, 2008

BUILDINGS

- **Palace of Justice**
- Bucharest
- 1890
- Extensive restoration between 1992 and 2005

The building was designed in the French neo-Renaissance style. The main façade is dominated by a full-height central block, while the main entrance is highlighted by six massive pilasters. Between these, four allegorical statues, placed in their own niches, symbolise Law, Justice, Justness and Truth. Two further statues placed on either side of the central clock represent Strength and Prudence. These are the works of Karol Storck the younger. The interior, with its impressive proportions and majestic columns, contains the so-called 'room of lost steps', which occupies a quarter of the entire building. At both ends, monumental marble stairs lead further into the building.

The main structure consists of high-quality load-bearing masonry with steel joist floors and vaulted brick infill in most parts. The symmetrical design has ensured excellent seismic behaviour. An extension was added in 1934-1937, followed by extensive consolidation and restoration works undertaken in the period 1992-2005.

Architecture: Arch. Albert Ballu; Architectural supervision and interior design: Arch. Ion Mincu
Construction: Eng. Nicolae Cuţarida building company
Consolidation project 1992-2005: Prof. Eng. emeritus Panaite Mazilu, Dr. Eng. Traian Popp, Prof. Dr. Eng. Radu Agent

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Romania

BRIDGES

- **Cernavodă Bridge**
- Constanţa County
- 1895
- Length of the bridge 4088 m

Photo: AGERPRES

This bridge was continental Europe's longest bridge at the time. A total of 5200 tons of mild steel for the super structure and 113 tons of hard steel for the bearings were used for the superstructure, while the foundations consisted of 1136 tons of steel for the caissons and 42,000 m^3 of masonry. The total length of the bridge is 4088 metres between the banks of the Danube. Innovations in this construction included Saligny's own inventions: a new system of beams on cantilever brackets, also known as continuous articulation, for the superstructure and the use of mild steel instead of puddle steel for the bridge deck.

Three bridges were built highly efficiently with a minimum number of deck elements and piles: the bridge over the Borcea, with three spans of 140 m each; Ezer Viaduct over Baltă, with one span of 195 m; and the bridge over the main Danube branch with four spans of 140 m. Only five types of steel deck elements were used, anticipating the idea of standardisation in construction. In 1970-1980 a second bridge was added parallel to the existing one to accommodate another railway line and the motorway.

Design engineer and site supervision: Eng. Anghel Saligny

Photo taken, with the author's permission, from the book „Lucrări publice din vremea lui Carol I" by Nicolae Noica, 2008

Romania

BUILDINGS

- **Palace of the Saving and Deposits Bank**
- Bucharest
- 1900
- Neo-Renaissance architecture

Photos taken, with the author's permission, from the book „Lucrări publice din vremea lui Carol I" by Nicolae Noica, 2008

Located in the central historical zone, the palace presents a symmetrical façade distinguished by its sumptuous entrance, crowned by an arch supported on either side by twin columns in the Composite style. The monumental steel and glass cupola, in the neo-Renaissance style, covers the dome over the central hall in which the bank's counters operate. The volumes of the four corners of the edifice, decorated with gables and coats of arms, are covered in smaller domes in the same style.

Architecture and works coordination:
Arch. Paul Gottereau, Ion N. Socolescu

Palace of the Saving and Deposits Bank

Romania

HARBOURS

- **Port of Constanța**
- Constanța County
- 1888 - 1909, first stage of construction
- Main port of Romania
- Europe's fourth largest harbour

Photos taken, with the author's permission, from the book „Lucrări publice din vremea lui Carol I" by Nicolae Noica, 2008

The Port of Constanța is Romania's main port to the Black Sea and Europe's fourth in terms of importance. Several stages can be identified in the construction. In 1888, following a unitary plan, the first construction stage was begun on the site of the old Tomis port with protective dams and quays of 8.25 m depth surrounding an area of 199 ha. The design project was awarded to a foreign company, yet detailed by the engineer Anghel Saligny.

In 1909 the main works were completed. The dig measured 1377.5 m in length, and the area of the basin was 60 ha, at a depth of 8.25 m, with the exception of the petrol basin, which was 9.25 m deep. After World War I, work started on a series of extension projects. New additions to the silos, a maritime railway station, stores, a grain exchange and the bay for the floating dock were built. In 1939 the floating dock 'Constanța', at 8,000 tons of lifting capacity, was brought from Lübeck, Germany.

The second stage (1958-1965), in which new quays, stores, deposits, workshops and rail tracks were built, new port machine equipment was installed and the shipbuilding site was modernised, constitutes what is known today as the 'old port'.

The third stage (1962-1980) is characterised by the extension towards the south on an area of around 523 ha called the port of 'Constanța Nord', including specialised zones for petroleum products, minerals, grain, containers, laminates and general goods.

The fourth stage (1976) resulted from demand for increased goods-handling capacity, and especially access for ships of larger tonnage. Thus 'Constanța Sud' was built, which can handle ships of up to 250,000 tdw. This extended the port area to a total of 3,626 ha, measuring around 4 km in width and occupying a coastline of around 6.5 km in length.

Anghel Saligny Statue

Romania

BUILDINGS

- **Lucian Blaga National Theatre**
- Cluj - Napoca (Klausenburg)
- Cluj County
- 1906
- Built in neo-Baroque style

Photos: AGERPRES

The Lucian Blaga National Theatre in Cluj is the most important theatrical institution in Transylvania and one of the most prestigious in Romania. The building, built between 1904 and 1906, was conceived in a neo-Baroque style, with the lobby decoration inspired by the Vienna Secession. The auditorium has a capacity of 928 and 3 rows of loggias. The inauguration of the Cluj National Theatre took place on 1 December 1919.

Architects: Hermann Helmer, Ferdinand Fellner

Romania

BUILDINGS

- **Black Vulture Palace, Oradea**
- Bihor County
- 1908
- Multifunctional building with Vienna Secession architecture

Photos: AGERPRES

The building is sited on a street corner, with a tall ground level and four upper floors. Between its parts a glazed arcade gives access to Independentei Street, Unirii Square and Vasile Alecsandri Street. The main elevation on Unirii Square is asymmetrical, formed by two unequally large building elements, which best illustrates the Secession Style.

The frontage of the building on Independenței Street is more ordered and austere. The central motif is represented by a projecting volume articulated in three parts, ending with three dormers with stained-glass windows decorating the gable ends. The stained-glass windows with the black vultures were executed in 1909, in the workshop of Oradean craftsman K. Neumann. The Black Vulture Palace is the most significant building of its style in Oradea.

The palace was designed as a multifunctional building containing, at the time of its inauguration, a casino, hotel, offices and a restaurant, all grouped in three asymmetrical structures. Currently the premises house a 47-room hotel, an 80-seat conference hall, a wellness centre, a cinema, clubs, some shops and a bank.

Architects: Komor Marcell and Jakob Dezső
Builder: Sztarill Ferenc

Romania

BUILDINGS

- **Assembly of the Administrative Palace, Palace of Culture**
- Târgu Mureș - Mureș County
- 1907-1913

Photos: AGERPRES

The Administrative Palace building, presently the Prefect's office and County Council, was inspired by Renaissance architecture (Sienna Town Hall). For this purpose, a campanile with a clock was constructed on the north side, rising to 60 m. The architectural style is Secession. The volume of the main building, with no tower, suggests a tent, and at the entrance to building there is a portico with a balcony, the place from which the mayor used to speak to the people.

The façades are elegant, with simple walls decorated with enamelled ceramic panels representing floral or zoomorphic motifs of popular inspiration. Diadem frontons at the roof cornice and enamelled tile by Zsolnay at the roof are arranged in geometric patterns. The most characteristic compositional vertical element remains the campanile, directly inspired from the shape of slender clock towers of wood churches from Transylvania. Square shaped, the tower has a cantilevered loggia and a row of columns that support a sharp pyramidal roof. The inside is distinguished by the coves mounted on star-shaped ribs and columns with composite column heads that support them.

Architects: Komor Marcell and Jakab Dezső

The Palace of Culture, the most representative building of Transylvanian Secession, is imposing both inside and out. The roof is covered with majolica produced by Zsolnai (Pecs, Hungary), famous for its porcelain objects.

The palace houses a concert hall with 800 seats, a mirror room, small room, picture gallery, a county library that owns rare and valuable books and the Conservatoire (nowadays the County Museum). The surfaces of the inner hall, with a length of 45 m, are Carrara marble and delimited by two Venetian mirrors. The "Mirror Room" illustrates exactly the characteristics of Secession style. It was named after the two groups of three crystal mirrors, symmetrically positioned on the walls from the ends of the room. Its special charm is still assured by the 12 stained glass windows, designed by Thorozkai-Wigand Ede and Nagy Sándor, that entirely cover the wall facing the street.

Architects: Komor Marcell and Jakab Dezső
Interior plans, execution of bas-reliefs and frescos at the entrance: Körösfői Kriesch Aladár
Construction: Grünwald Brothers and Schiffer Company

Romania

Photos: Cătălin Cădan

Orthodox and Roman Catholic Cathedrals Architectural Complex

BUILDINGS

- **Cathedral of the People's Reunification and Alba Iulia Fortress**
- Alba Iulia - Alba County
- 1922
- 58 m clock tower
- Oldest fortress in Transylvania

The Monument of Unification, the cathedral in Alba Iulia, was built on the occasion of the coronation of King Ferdinand and Queen Maria on 15 October 1922. The architectural style belongs to the Romantic movement initiated in Romania in the last decades of the 19th century and aimed at utilising the architectonic and decorative elements from the period of rulers Matei Basarab and Constantin Brâncoveanu.

The building plan is based on a Greek cross pattern. The cathedral is a part of an architectural grouping consisting of two pavilions on the east side and two smaller ones on the west side. The complex is dominated by a 58 m clock tower topped by a bell-shaped cupola on a row of columns.

Cathedral plan: Arch. Gheorghe Ştefănescu
Architects: a group led by Ion Mincu, Petre Antonescu
Constructions works: Eng. Tiberiu Eremia
Interior fresco: Costin Petrescu

Cathedral of the People's Reunification and Alba Iulia Fortress

The whole architectural complex, the cathedral and various buildings were erected in the western part of the Alba Iulia Fortress, constructed during the reign of Emperor Karl VI of Austria, on the ruins of the ancient Roman Apulum site or Bălgrad of the Middle Ages. The fortress, with three monumental gates, includes historical and cultural edifices of special importance. Thus, the Orthodox Cathedral of the Great Union from 1918, a nearby Roman Catholic cathedral, contributes to an imposing architectural complex. The Roman Catholic cathedral, of great architectural and artistic value, is the oldest medieval edifice preserved in Transylvania.

The Gate III of the Fortress

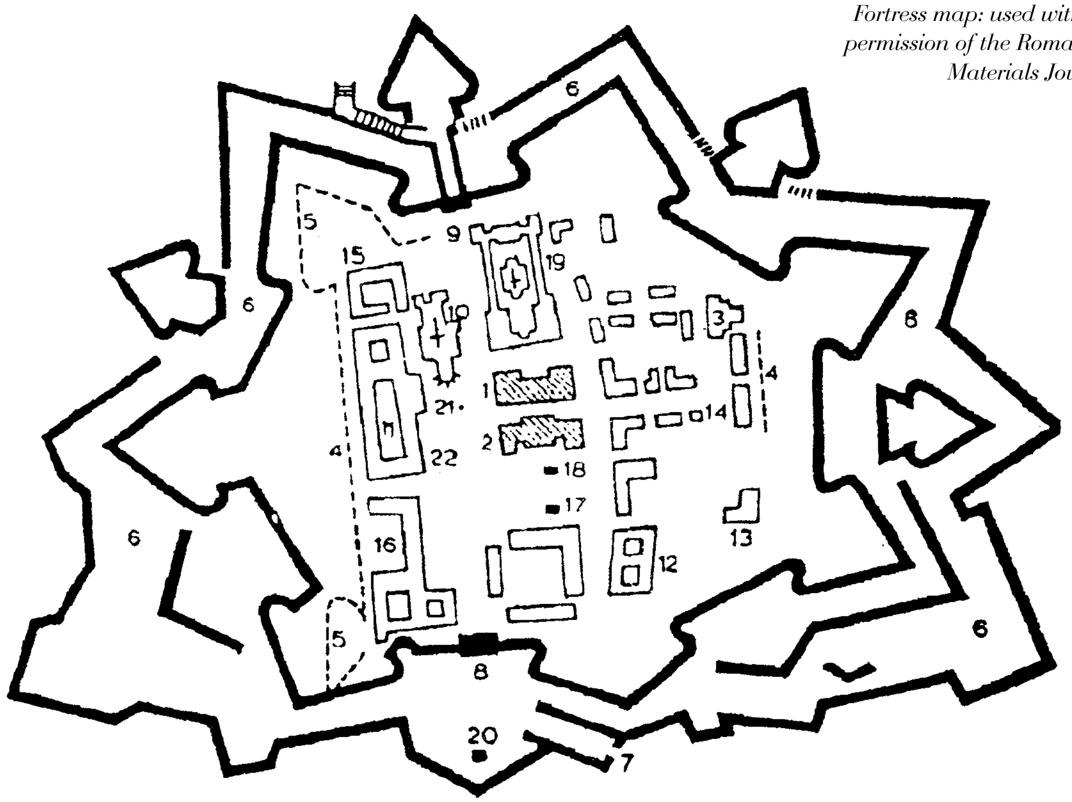
Fortress legend:

1- Union Museum; 2- Union Room; 3- 'Batthyaneum' Library; 4- Roman camp; 5- Old Fortress; 6- Fortress bastion, 15- Episcopal Palace; 19- Ortodox Cathedral; 20- Obelisk 'Horea, Cloşca and Crişan'; 21- Equestrian statue of Mihai Viteazul I

Also in the Fortress: Union Museum, Union Room, equestrian statue of Mihai Viteazul, obelisk dedicated to the martyrdom of Horia, Cloşca and Crişan, and the documentary library 'Batthyaneum', known worldwide for its collections of manuscripts, incunabula, publications, medieval religious objects, coins and the Codex Aureus, a part from Gospel of Lorsch.

Gate I of the Fortress has the shape of a triumphal arch with three entrances and is constructed from carved stone with decorations in the Baroque style.

Gate III with the 'Cell of Horia' is conceived as a massive double triumphal gate, with the façade dominated by the equestrian statue of Karl VI, during whose reign the fortress was constructed.



Fortress map: used with the permission of the Romanian Materials Journal

Romania

Photos: Adrian Moisei

BUILDINGS

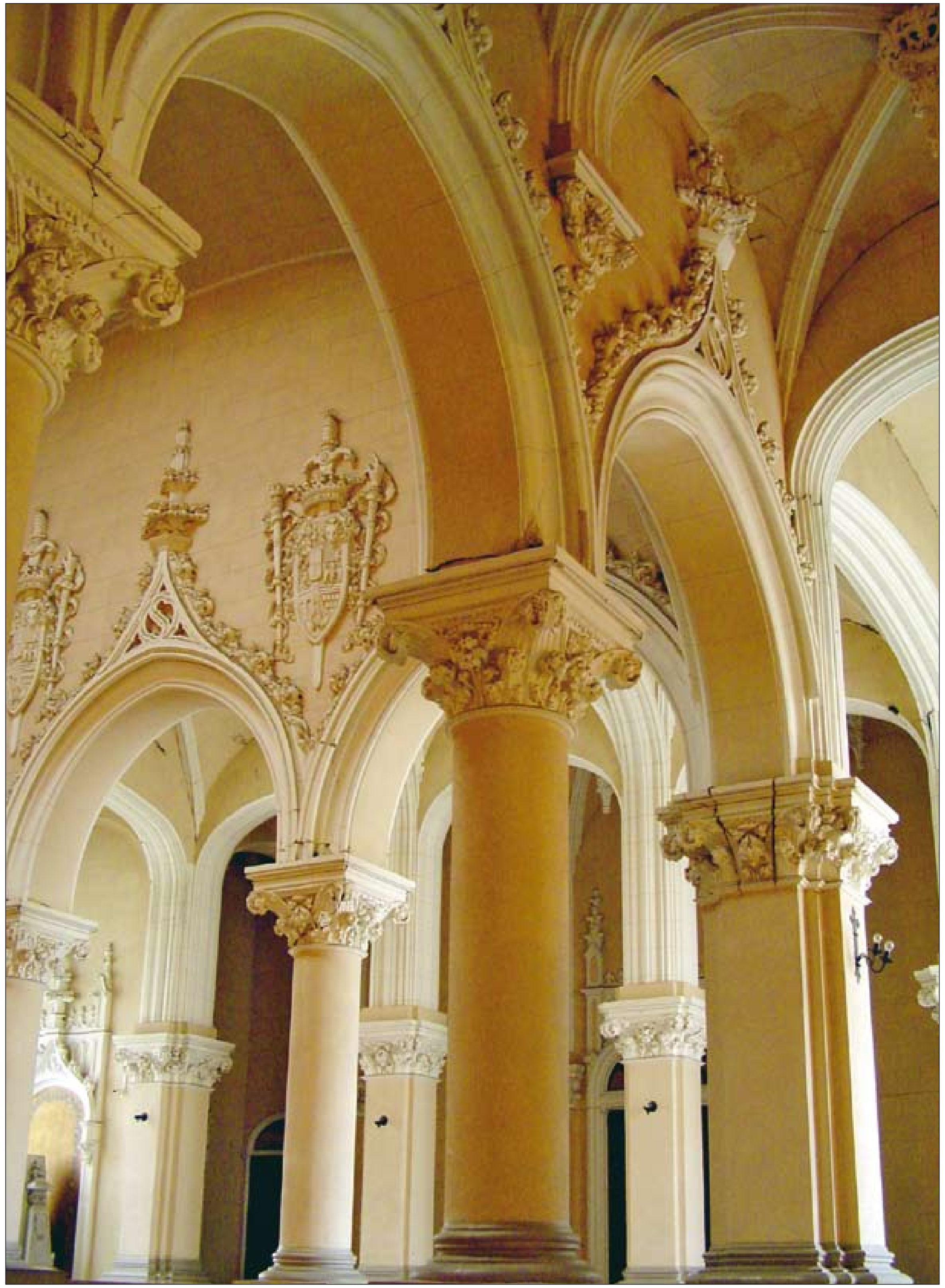
- **Palace of Culture**
- Iași
- 1906 - 1925
- Built in the neo-Gothic style

The Palace of Culture in Iași is considered the symbol of the town and was built partly on top of the ruins of the medieval princely court. The palace's basements were also partially reused from the period of Lord Alexandru Moruzi (1806-1812) and refurbished by Mihail Sturza (1841-1843).

The building was inaugurated on 11 October 1925 and served as the Palace of Justice until 1955, when it was designated to accommodate the most important cultural institutions of Iași, combined today as the 'Moldova' National Museum Complex of Iași. It is built in the neo-Gothic style and represents one of the last expressions of the Romantic style in formal architecture. From the decorative point of view, the figurative mosaic in the central hall is remarkable, in which representations of a Gothic bestiary are arranged concentrically: the two-headed eagle, the dragon, the griffin, the lion. Above the hall a skylight can be found, which originally contained a greenhouse.

In the construction of the palace, stone blocks were replaced with less expensive material, yet in the decoration of some rooms, a material patented by Henri Coandă was used for the first time – boiscement, which imitates the appearance of oak. The Voivode (Lord's) Hall is striking in its use of decorative copper fittings. The building was endowed with the service amenities of its time: electric lighting, pneumatic heating, ventilation systems, thermostats and vacuum cleaners, all of which were served from a central plant located in the basement.

Architect: I. D. Berindei



Romania

BUILDINGS

- **Orthodox Metropolitan Cathedral**
- Timișoara, Timiș County
- 1936 - 1945
- Designed in the Byzantine style

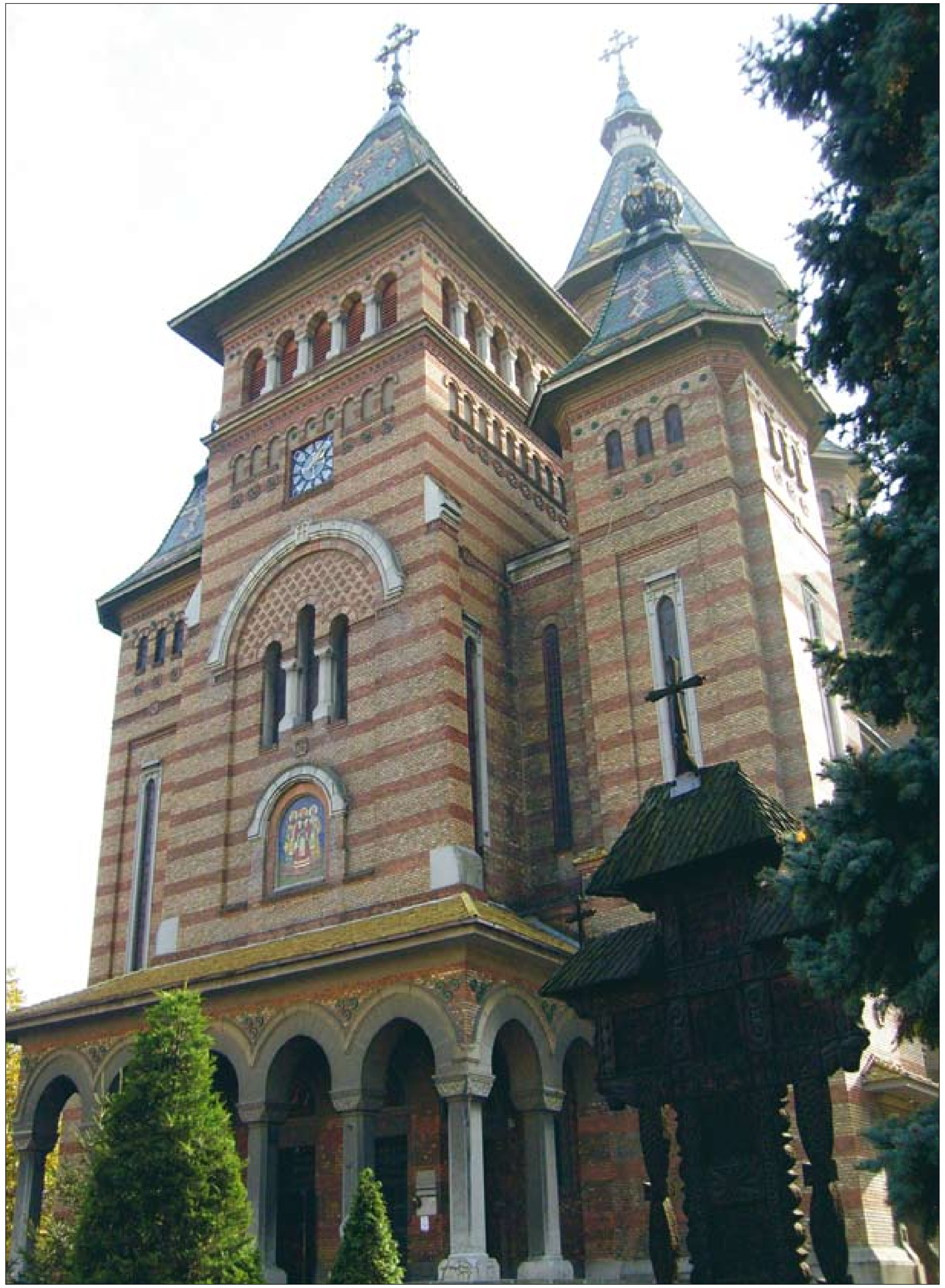
Photos: ©ProCom – www.procom.org

The building is 63 m long and 32 m wide, and its main tower rises to a height of 83.7 m. The architecture is designed in the Byzantine style with decorative elements similar to those of Hagia Sofia in Istanbul (Constantinople) and other elements inspired by Moldovan churches (e.g. Saint George of Hârlau).

The tower roofs are covered with coloured ceramic tiles. The steps, base, columns, pillars and decorative elements around openings are carved in natural stone. The façades consist of red and yellow face bricks joined with glazed plates and painted alcoves. The cathedral impresses with its perfect lighting from the sixteen windows of the main cupola and from the thirty-two lateral windows. This edifice was erected on swampy ground, on a concrete foundation slab several metres thick, which is supported by 1186 piles.

The cathedral's basement contains a medieval art museum with a valuable collection of 17th to 18th century glass and wood icons, Orthodox cult objects and a collection of first editions in Romanian.

Architect: I. Traianescu (student of Ion Mincu, architect)



Romania

Photo: AGERPRES

BUILDINGS

- **Free Press Building**
- Bucharest
- 1954
- Largest office building in Romania

The Free Press Building is the country's largest office building. The construction extends over an area of 23,000 m², the total length of corridors amounts to more than 3 km, and the number of rooms is over 6,000. The building itself is formed by four wings which shelter a large inner court, plus two U-shaped volumes, linked by a central front.

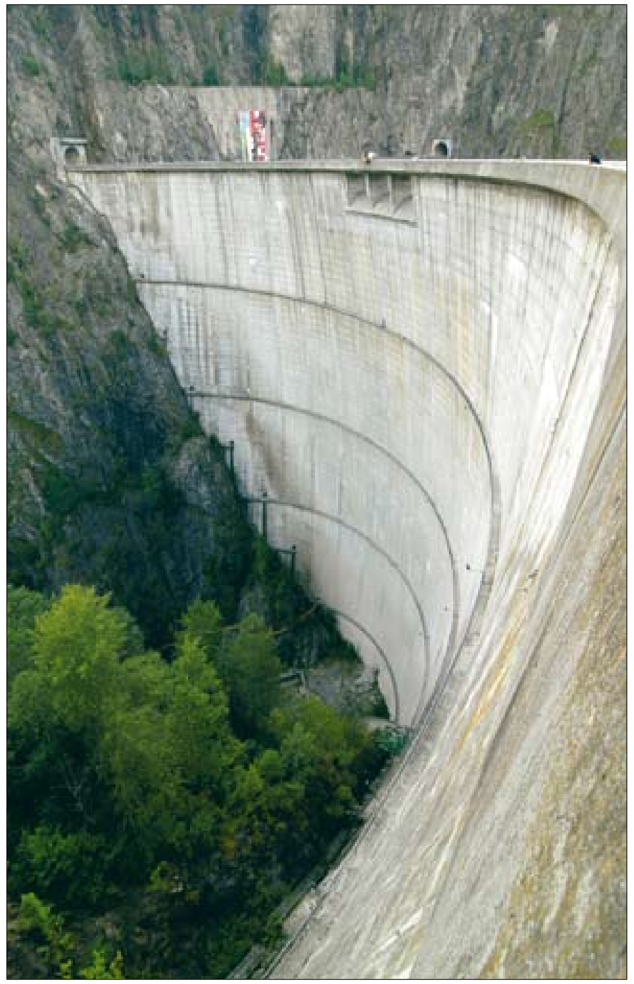
The Free Press Building was inspired by Socialist-Realist architecture, using elements from Romanian art. The four towers which mark the outer limits of the overall composition can also be seen in the Dragomirna or Sucevița monasteries. A technical innovation at the time was abandoning the old riveting method, replacing it with the superior welding method. Thus, for the first time in Romania, it was possible to create a unitary frame. Another innovation used for the first time in Romania was to perform structural calculations for the building in order to resist earthquakes by taking into account the experience of Romanian engineers after the earthquake of 1940. The plans were drawn up by a large team of architects and engineers led by the architect Horia Maicu. The structure was designed by a group of engineers coordinated by Prof. Eng. emeritus Panaite Mazilu.

Romania

DAMS

- **Vidraru Dam**
- Argeș County
- 1965
- One of Europe's highest dams

Photos: AGERPRES



This dam is concrete with a double curvature carried out from 22 vertical plots, having a height of 166.60 meters and a crest length of 307 meters, and crossed by nine horizontal inner galleries. The construction of the dam took five and half years. A total of 42 km of underground galleries were drilled and 1,768,000 m³ of rock were excavated, from which around 1,000,000 m³ were under ground. In all, 930,000 m³ of concrete were poured, of which 400,000 m³ were under ground, and 6,300 tons of electro-mechanic equipment were mounted. The Vidraru storage lake, located on the Argeș River, has a total volume of 465 million m³. The normal level of retention is 830.00 meters above sea level (mdM), the lake having, at this level, a surface area of 870 hectares and a length of 14 km. Vidraru Dam was, at the time it was inaugurated, the fifth largest in Europe and the ninth in the world among similar constructions.

Project: Prof. Dr. Eng. Radu Prișcu

Romania

Photo: AGERPRES

HYDROPOWER PLANTS

- **Iron Gates Hydro-energetic System**
- Caraș - Severin County
- 1972
- Largest HPP on the Danube
- Total power 2160 MW plus 580 MW

The Iron Gates Hydro-energetic System administrates the largest hydro-centre on the Danube River: Iron Gates I (1972) and Iron Gates II (1984). Both hydro-centres are operated in partnership with Serbia and have a capacity of 2160 MW and 580 MW, respectively. Iron Gates I and II may dispose of a utilisable discharge of 8700 m³/s. Iron Gates I is located 15 km upstream of the town of Drobeta Turnu-Severin, and Iron Gates II 60 km downstream.

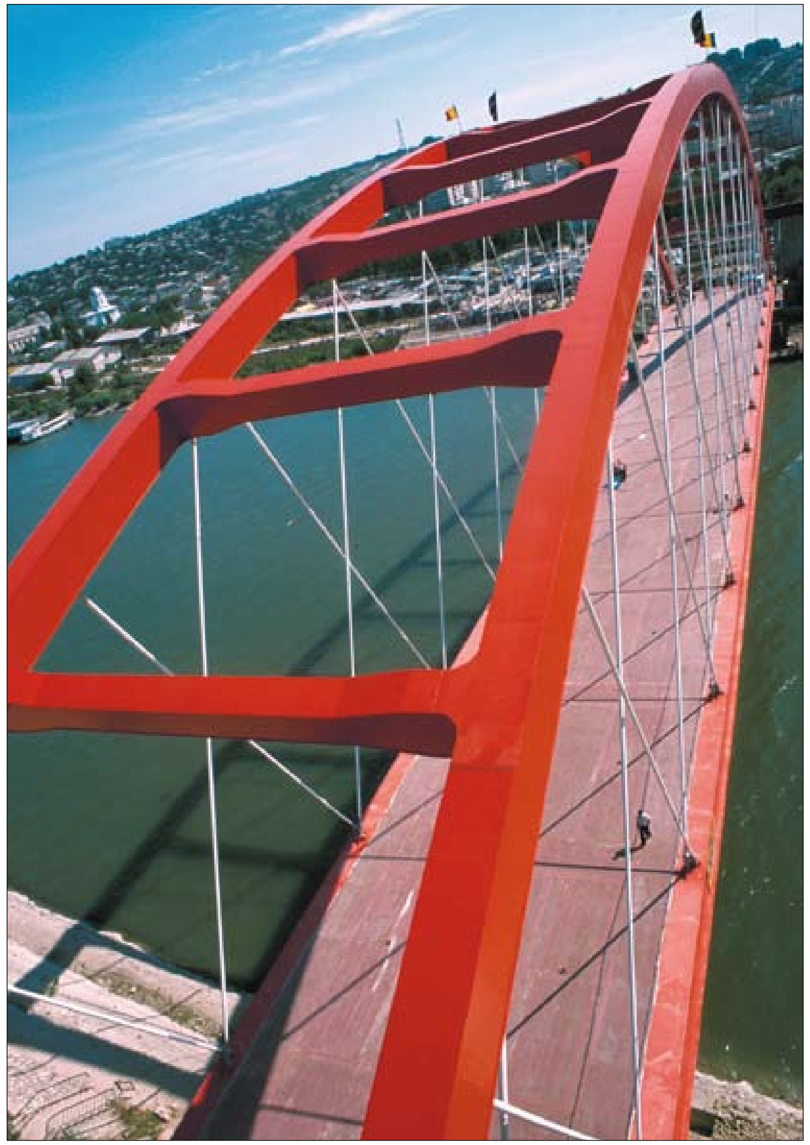
Navigation on the Danube is assured by sluices on both banks, having a traffic capacity of 52.4 million tons/year for locking in each direction and 37.2 million tones/year for locking in both directions. Iron Gates I is one of the largest hydro-technical constructions in Europe and the largest on the Danube. The storage lake, with a volume of over 2200 million m³, extends from the dam up to the confluence with Tisa River. The lake contains mainly the zone of the Danube Rift, the biggest rift in Europe, enclosed between the localities of Baziaş and Orşova.

Romania

CANALS

- **Danube - Black Sea Canal**
- Constanța County
- 1975 - 1984
- 300 million m³ of soil excavation
- One of the largest in Europe

Photos: AGERPRES



The Danube - Black Sea Canal connects the maritime harbour of Constanța with the fluvial port of Cernavodă, shortening by approximately 400 km the goods route from the Black Sea to Danubian ports in Central Europe.

The construction required the excavation of around 300 million m³ of soil and rock, the pouring of over 4 million m³ of concrete and reinforced concrete, and execution of 24,345 tons of steel works. Technical characteristics: length 64.4 km, width 90 m, depth 7 m, maximum draught 5.5 m, clearance height at bridges 16.5 m. According to EEC-UNO standards, the Danube - Black Sea Canal is situated in the sixth class of inner canals, the highest class for this kind of construction. By opening the Main - Rhine Canal in 1992, a direct navigable connection between Constanța and Rotterdam was achieved. The main advantage of the Danube - Black Sea Canal consists of the direct connection with Constanta, the largest maritime harbour on the Black Sea and one of the largest in Europe.

Danube - Black Sea Canal

Slovakia

RELIGIOUS BUILDINGS

- **Wooden Churches in the Carpathians**
- Northeastern Slovakia
- 17th - 18th Century
- UNESCO World Heritage

Text: Ing. Milan Fischer, P. Eng.

Throughout centuries numerous wooden churches were built in villages of Slovakia's Eastern Carpathian mountains. Construction of these churches is unique, as they interpret and utilise religious architecture of their period in local building principles. They are built of local timber, in log-cabin styles, many without nails or any metal construction elements. They are rare, and as such eight of them were recently added to the UNESCO World Heritage List.

Two of these churches are Roman Catholic, three Protestant and three Greek Catholic. They all represent examples of local as well as regional sacred constructions marked by the meeting of Byzantine and Latin cultures. In all of these UNESCO World Heritage designated churches, religious services/ceremonies are performed.

Photo: Milan Kapusta, TASR

Slovakia

Photo: Miroslava Cibulková, TASR

BUILDINGS

■ **Primate Palace**

■ Bratislava (Capital City), Southwestern Slovakia

■ 1778 - 1781

■ Architectural - engineering jewel of Bratislava

Text: Ing. Milan Fischer, P. Eng.

The Primate Palace, the original seat of the archbishop, is one of the architectural–engineering jewels of Bratislava. It was built in the historical city centre in 1781 after 3 years of construction. The designer was Melichor Hefele.

The Palace was constructed in elegant Rococo style with well a thought out disposition of design. The roof of the Palace is decorated with allegorical statutes. The archbishop's coat-of- arms placed above the main entrance is topped by a cardinal's hat made of iron and 1.8 m in diameter. The interior of the Palace features on the first floor impressive State Rooms and the Hall of Mirrors. The Palace also houses a unique series of six English Gobelin tapestries from the 17th century depicting the tragic love of Hero and Leander.

Throughout years the Palace became the place were significant historical events took place, including:

- in 1805 The Treaty of Bratislava was signed following the battle of Austerlitz in which Habsburg Austria lost Napoleon's France,
- in 1848 a law was signed abolishing serfdom in the Slovak territory,
- in 1968 a meeting took place of the leaders of the Warsaw pact in advance of their armies invasion of the country,
- in the 1990s it housed the office of the President of the Slovak Republic.

At present it is part of the Bratislava City Hall. It is open to visitors.

Slovakia

Photo: Radovan Stoklasa, TASR

BUILDINGS

■ **Bojnice Castle**

■ Bojnice, West - Central Slovakia

■ 1899 - 1909

■ Slovak National Cultural Monument

Text: Ing. Milan Fischer, P. Eng.

Bojnice Castle is situated in the west-central region of Slovakia. It was built, as almost all castles, by construction activities spanning many years throughout many stages. To consider this case unique and noteworthy is its romanticist, visionary renovation from 1899 to 1909.

This broad–minded renovation was headed by the castle owner, a great art lover and collector of antiques, count Jan Palffy, who intended to produce a spectacular memorial for himself and his family by imitating castle architecture from Western Europe. As such it was decided to model it on the Gothic chateaux on the Loire River in France and for actual work to engage well-known architect Josef Hubert.

Cooperation between Palffy and Hubert resulted in impressive renovation work in the interior as well as exterior of the castle. Exterior renovation, mainly roof lines and facades, are give the castle a total new fairytale look and creating one of the most attractive castles in Slovakia. The castle now is owned by the state and in 1970 was proclaimed a Slovak National Cultural Monument. It is continuously open to the public.

Slovakia

Photo: Vladimir Benko, TASR

BUILDINGS

- **Milan R. Stefanik Monument**
- Bradlo, Western Slovakia
- 1927 - 1928
- National Monument

Text: Ing. Milan Fischer, P. Eng.

The Milan R. Stefanik Monument was constructed to honor and provide a final resting place for General Milan R. Stefanik, a Slovak hero who was the most accomplished builder of the Slovak nation during the First World War. General Stefanik spent years living abroad and died in a tragic airplane crash in Slovakia in 1919 upon his return to his homeland at the end of the war.

His monument was designed on the mountain hill top, Bradlo, near the place of his birth. The author of the monument was prominent Slovak architect Dušan Jurkovic.

The General Stefanik monument is situated in an east-west orientation and consists of two cut down pyramids and a three level pyramid which contains the remains of General Stefanik. Upper terrace dimensions are 93 x 62 m and 45 x 32 m. On the corners of the upper terrace are situated 12 m high obelisks.

The whole monument is built using massive travertine ashlars.

Slovakia

Photo: Milan Kapusta, TASR

INFRASTRUCTURE

- **High Tatra Cableway**
- High Tatra Mountains, North - Central Slovakia
- 1936 - 1941
- Total length 5,980 m

Text: Ing. Milan Fischer, P. Eng.

The High Tatra mountains – Vysoke Tatry in Slovak – are the most prominent mountains in Slovakia. They are well-known for their recreational resorts and facilities, spas, tourism grounds, mountaineering and leisure activities. For years the High Tatras keep attracting numerous visitors, local and international alike, which likely, indirectly, led to the decision to construct the cableway access to the top of the second highest peak, Lomnicky Stit, with an elevation of 2,632 m.

Construction of the cableway system was carried out in years 1936-1941 by the Wiesner Co. The most prominent Slovak architect Dusan Jurkovic was in charge of the design of the Stations. The whole ascent to the peak was constructed in two sections; one from Tatranska Lomnica to Strbske Pleso and the other from Strbske Pleso to Lomnicky Stit. Each section had different original parameters; length, line gradient, number of tower supports (9/1), cabin capacity (31/16). Running speed however was the same 4 m/s. The total length of the line with one transfer at Skalnate Pleso was 5,980 m.

The cableway system to Lomnicky Stit is still in operation, although some repair and reconstruction works were carried out in 1988, 1989 and 2000.

For the last two years the cableway system has had new owners who intend to invest a significant amount of money to modernise the whole operation.

Slovakia

New Bridge, Bratislava

BRIDGES

- **New Bridge (formerly SNP Bridge)**
- Bratislava (Capital City), South - Western Slovakia
- 1967 - 1972
- Main span 303 m
- A restaurant is located on the top of the pylon

Text: Ing. Milan Fischer, P. Eng.

This road bridge is built over the Danube River in Bratislava. At the time of its construction, this bridge was only the second one connecting two important parts of the city on Danube River sides. The bridge designer was Dopravoprojekt Co., the main contractor Doprastav Co., both of Bratislava.

It uses steel suspended construction, with spans: 74.8 m, 303.0 m, 54.0 m. The main span is suspended on cables which lead through a single inclined pylon to the anchor block. The pylon is in an 'A' configuration and has a restaurant on top, 80 m up, in the form of a UFO disk. Access to this restaurant is by an elevator operating in one leg of the pylon. The bridge is 21 m wide, with traffic capacity of 4 lanes. Unique is also the location of sidewalks, which are positioned on both sides of the bridge below the main deck.

The bridge is technically remarkable and unique and as such was declared the Building of the 20th. Century in Slovakia. It is still in continuous use.

Photo: Archive of TASR (The News Agency of the Slovak Republic)

Slovakia

BUILDINGS

- **Eastern Slovakia Ironworks -VSŽ**
- Košice - Eastern Slovakia
- 1965 - 1975
- The biggest steel producer in Slovakia

Text: Ing. Milan Fischer, P. Eng.

The Eastern Slovakia Ironworks (known as VSŽ) was constructed just south of the eastern Slovakia metropolis Košice. The construction company Hydrostav of Bratislava was established in 1951. In 1972 the company Hydrostav Košice inherited construction of Eastern Slovakia Ironworks. Hydrostav Košice consequently completed this plant in 1975. When completed it became one of the largest industrial colossuses in the country.

In 2000 VSŽ was acquired by U.S. Steel Corporation and VSŽ continues its operation as U.S. Steel Košice. It is the biggest steel producer in Slovakia, producing an annual average of five million US tons of steel.

This steel production and processing plant also shares in the development of the automotive industry by supplying high-quality steel sheeting. It is the largest country employer (in excess of 15,000 employees) and one of the top three exporters.

Photo: Svätopluk Písecký, TASR

Slovakia

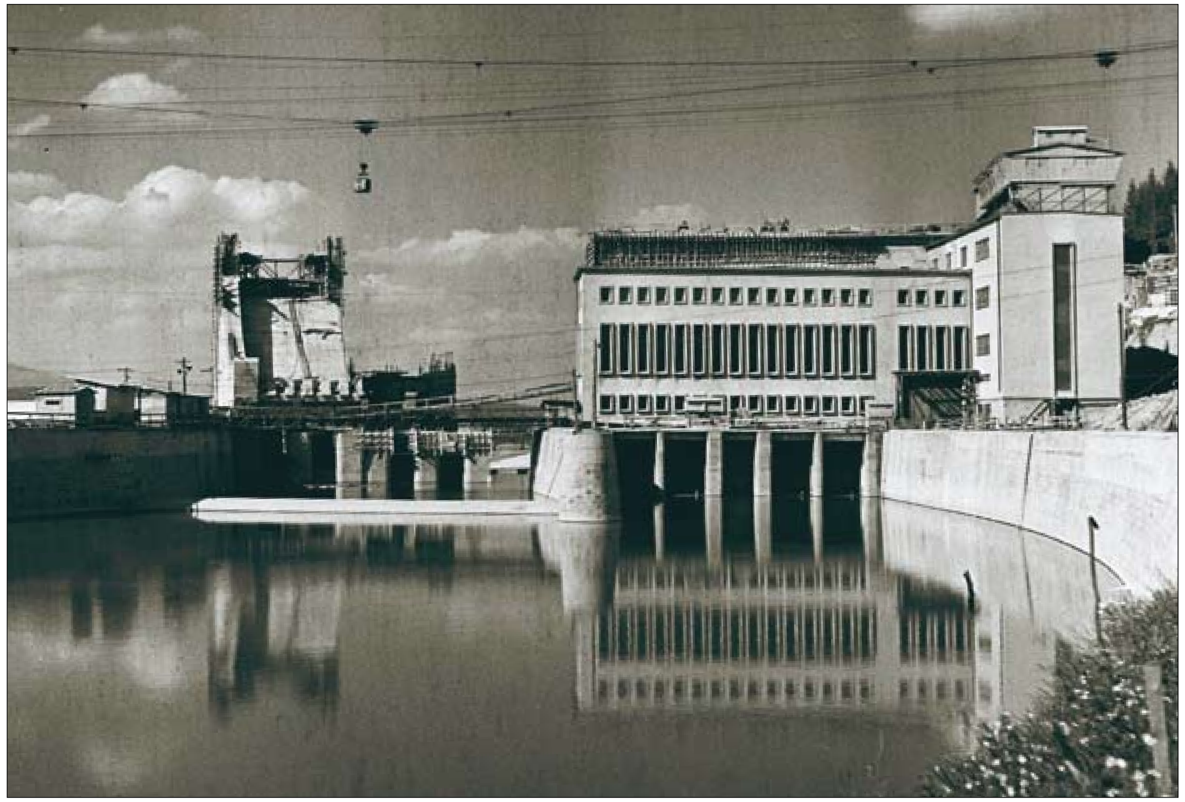


Photo: Koloman Cich, TASR

HYDROPOWER PLANTS

- **Vah River Hydroelectric Cascade**
- North - Central Slovakia
- 1932 - 1989
- Total installed output 800 MW

Text: Ing. Milan Fischer, P. Eng.

With the advance of industrialisation and general development of the country there are growing requirements to provide adequate energy supply. In the first half of the 20th century electric power was supplied by hydropower plants. Slovakia was well suited, having abundant water supply in its 9 river catchments, with the largest being the Vah River catchment covering 34% of the area of Slovakia. The Vah River in its entirety of almost 400 km flows through Slovakia providing a theoretical 370 m head for power generation.

Consequently in Slovakia complex plan was implemented for construction of a system – a cascade of hydropower plants on Vah River. The first hydropower plant of this cascade was built in 1932-1936 at Ladce by the firm Pittel and Brausewetter. Afterwards followed others at Hricov, Miksova, Nosice, Dolne Kockovce, Trencin-Skalka, Kostolna, Nove Mesto, Horna Streda, Madunice and Kralova. Furthermore, as a part of this hydroelectric system hydropower plants were constructed at Orava, Tvrdosin, Nova Bystra, Krpelany, Liptovska Mara and Benesova, located in the headwaters of the Vah River. These in addition to electric energy production regulate an adequate water regime for the downstream plants of the cascade.

The total installed output of the cascade is almost 800 MW. The system as such in addition to providing electric power also contributes to other uses of the Vah River, including flood control of adjacent lands.

Slovakia

Photo: Štefan Kačena, TASR

HYDROPOWER PLANTS

- **Gabcikovo Multi - Purpose Hydro Development**
- Gabcikovo, South-Western Slovakia
- 1978 - 1992
- 8 Kaplan turbines installed

Text: Ing. Milan Fischer, P. Eng.

The multi-purpose hydro development at Gabcikovo is one of the largest civil engineering projects ever constructed in Slovakia. It is situated on the Danube River some 40 km downstream from Bratislava. The concept of the project was developed by Prof. Ing. Peter Danisovic. The chief designer was Hydroconsult Co. and the main contractor Hydrostav Co. both of Bratislava, the contactor for technological and energetic components CKD Blansko Co.

Main purposes of this development consisted of:
- utilisation of the hydropower potential of the Danube River
- improving river navigation conditions to accommodate large vessels
- reducing danger of catastrophic floods in adjacent hands
- improvement and stabilisation of the water regime in the Danube with corresponding environmental / ecological aspects
- development of recreational possibilities, tourism and water sports

Subsequently Gabcikovo Multi-purpose Hydro Development was constructed with main elements being: inlet reservoir / channel, one of the longest in the world, hydropower plant, 2 navigation locks and tailrace. The hydropower plant has 8 Kaplan turbines with installed output 720 MW, which provide 10-20% of electric power used yearly in Slovakia. The navigation locks have dimension: width 34 m, length 275 m each. They provide for 16-23 m differences in water elevation.

The Gabcikovo Multi-purpose Hydro Development provides complex utilisation of the Danube River potential. It is continuously in operation, bringing into reality a practical application of civil engineering in the context of the second largest river in Europe.

Slovenia

DAMS

- **Idrija Dams - Idrijske Klavže**
- In vicinity of the town Idrija
- 1767 - 1812
- Klavže - The Slovenian pyramides
- Technical monument

Text by Branko Zadnik

Throughout its five centuries, the mercury mine and the city of Idrija, Slovenia, needed vast quantities of wood, and for that reason forestry was from time immemorial of substantial importance. The wood was used as pit wooden material, round timber, construction wood and fuel wood.

The river basin of the upper Idrijca River is rich with forests, which had been wisely managed in the past so that there was never a lack of timber. The forests, however, were located quite far away and were frequently fairly inaccessible, thus the natural waterways turned out to be the most appropriate means of transport. Drifting of wood started in the end of the 16th century and successfully lasted as long as 1926 when catastrophic flooding severely damaged the wooden rakes in Idrija and in Spodnja Idrija.

In the beginning the water barriers were built as early as the 16th century. These constructions enabled sufficient water accumulation, independent of the whims of nature. Usually they waited fore extensive rainfall and the rise of the waters, yet the unstable territorial streams caused constant troubles.

In the mid 16th century the first "GRABLJE" (RAKES) – oblique slanting wooden barriers stretching across the river, where the drifting wood was stopped – were located at Lenštat in the middle of Idrija, in direct proximity to the mine and overlooking the confluence of the Idrijca and Nikova rivers.

Around the year 1770, new, monumental barriers made of brick and stone were built, to which in Napoleon's days, in 1812, they also added a dam at Ovčjak in the valley of the Kanomljica River. Puzzolanic cement was used as the binding material of the monumental structure of the walls and vaulted openings.

Mrak's klavže barriers on the Idrijca River formed an almost 800-metre-long lake, wherein 210,000 m^3 of water could be accumulated. By means of this barriers, some 13,000 m^3 of wood at the time could drift all the way to Idrija, which lies some 20 kilometres downstream. The capacities of the other klavže were distinctly smaller.

The drifting of wood to the "rakes" to the city was repeated each year, mostly in autumn, until 1926.

More information on the website:
www.muzej-idrija-cerkno.si

Photo Bogdan Kladnik

Slovenia

BRIDGES

- **Borovnica Railway Viaduct**
- Borovnica, 20 km west of Ljubljana
- 1850 - 1856
- At the time of its construction it was the largest two-track railway structure in the world
- Total length 561 m
- Destroyed during World War II

Text by Gorazd Humar

In 1830 the first public railway to use steam locomotives opened in England. Shortly afterwards the Austrian Empire, to which present-day Slovenia then belonged, began building new railway lines at a great rate. The most important of them was of course the Southern Railway (Südbahn), which between 1842 and 1857 connected the imperial capital Vienna to the Adriatic port of Trieste in gradual stages.

With great difficulties and obstacles, and under the leadership of the brilliant designer and engineer Carl Ritter von Ghega, one of the most modern railways in Europe was built. The largest and technically most demanding structure on the 500-kilometre line was the two-tier viaduct near the village of Borovnica (20 kilometres west of Ljubljana), better known as the Borovnica Viaduct.

Building the foundations of the viaduct's piers on more than 4000 oak piles driven into the soft marshy ground was a particularly difficult feat. The viaduct itself was built of stone (63,000 m^3) and specially shaped bricks fired in a brickworks next to the bridge itself. The arches of the viaduct contained 5 million bricks.

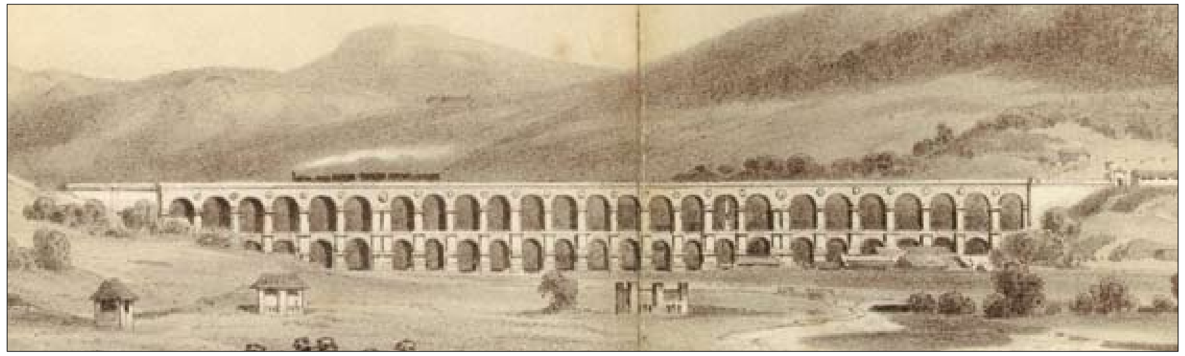
The 38-metre-high viaduct had two tiers. The lower tier had 22 arches and the upper tier 25 arches. The total length of the viaduct was 561 m.

At the time of its building, the Borovnica Viaduct was the largest two-track railway structure in the world. The only viaduct larger than it was the multiple-tier Göltzschtal Viaduct near Plauen in Germany.

Problems with the Borovnica Viaduct began when the draining of the Ljubljana Marshes at the end of the 19th century caused the wooden piles on which it was built to start to decay.

Later on, the Borovnica Viaduct was to experience a turbulent destiny. On 10 April 1941 it was blown up by Yugoslav army units as they retreated from the advancing Italian forces. A temporary steel Roth-Waagner bridge structure erected by Italian railway engineers allowed some traffic to cross the viaduct. The viaduct's fate was sealed by numerous Allied bombing raids in 1944 and 1945.

After the Second World War the badly damaged viaduct was no longer suitable for rebuilding. The remaining fragments of the great structure were gradually demolished. Today a single pier is all that is left standing to show where the Borovnica Viaduct once stood.



Slovenia

BRIDGES

- **Dragon Bridge** (Zmajski most)
- Ljubljana, over the River Ljubljanica
- 1900 - 1901
- First reinforced concrete bridge in Slovenia (Melan system)
- One of the largest of this type in Europe at the time
- Technical monument

Text by Gorazd Humar


Photo Bogdan Kladnik

The Dragon Bridge over the River Ljubljanica in Ljubljana is without a doubt one of Slovenia's best known bridges, not only because of the four dragon statues that adorn it, but also because of its architectural beauty and the technical value of the structure of the main arch. The bridge represents one of the most beautiful examples of Vienna Secession architecture from the turn of the 20th century. At the time of its construction it was also an exceptionally technically advanced bridge structure. The Dragon Bridge belongs to the early generation of reinforced concrete arch bridges built using the Melan system. This method of bridge-building, developed by the Czech engineer and pioneer of reinforced concrete Josef Melan of Brno, spread rapidly throughout Europe and the USA thanks to its simplicity. The basis of the system involves the preliminary construction of load-bearing truss arches capable of supporting the shuttering and the weight of the concrete during the concreting of the arch. The main span structure of the bridge consists of a three-hinged reinforced concrete arch with a span of 33.34 m. At the time it was built, this bridge had one of the largest spans of any reinforced concrete bridge in Europe built using the Melan system. The bridge's rich architectural design was the work of the architect Jurij Zaninovich.

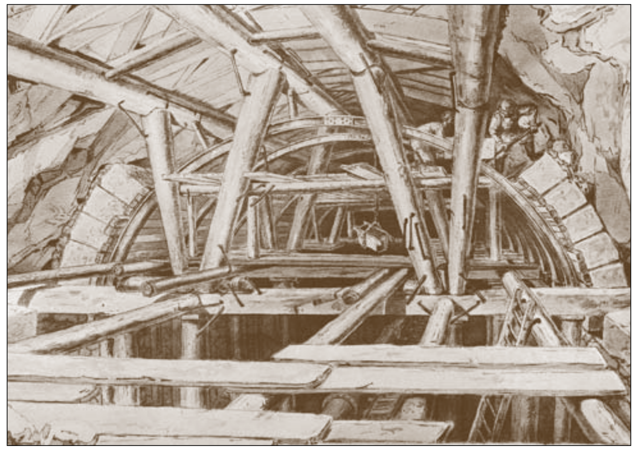
On 4 October 1901, two years after construction began, the Dragon Bridge was formally opened to traffic. Much of the credit for the building of the bridge belongs to the city's mayor, Ivan Hribar, who placed a plaque bearing a Slovene inscription on the bridge that was originally named the Jubilee Bridge of Emperor Franz Joseph I.

The Dragon Bridge was the first reinforced concrete bridge in Slovenia and one of the few examples of bridges of this type from the turn of the 20th century that is still open to traffic today. It would be impossible to imagine present-day Ljubljana without the Dragon Bridge, one of its greatest symbols.

The Dragon Bridge today enjoys protected status as a technical monument.

Dragon Bridge

Slovenia



TUNNELS

- **Bohinj Railway Tunnel**
- Bohinjska Bistrica - Podbrdo
- 1902 - 1905
- The longest Slovenian tunnel
  l = 6327 m
- First use of 3-phase electric current boring machines in tunneling

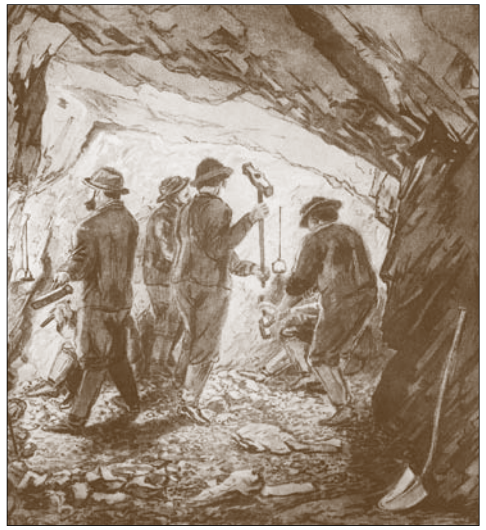
Text by Gorazd Humar

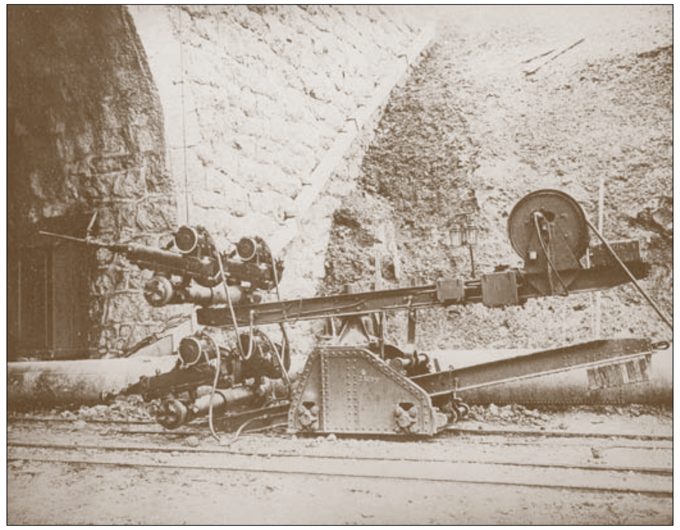
The Bohinj Railway Tunnel stands on the second railway line connecting Vienna and Trieste, which was opened to traffic on 19 July 1906. It is the key tunnel structure on the famous Bohinj Railway, a line with extremely demanding technical elements and numerous tunnels and bridges.

Construction of the tunnel began, following preliminary test excavations, in 1902. Work was directed by the famous tunnel-builder Giacomo Ceconi (1833–1910). To begin with, the tunnel was dug entirely by hand. Even the boring of the holes for the explosives was done by hand. Later, Siemens-Halske electric boring machines operating on 3-phase electric current were used – for the first time anywhere in the world. This greatly speeded up construction. Having faced extremely difficult geological conditions and frequent and abundant flooding caused by groundwater, the tunnel workers successfully broke through on 31 May 1904. The tunnel, which was designed for two-track traffic, was lined with solid stone blocks from nearby quarries. The total volume of stone built into the tunnel was 158,000 m^3.

Owing to strong lateral influxes of groundwater, the tunnel has frequently been flooded above the height of the railway tracks.

As a result of the demolition of the north tunnel entrance at the end of the Second World War, the tunnel is today 12 metres shorter than when it was built.





Bohinj Railway Tunnel

Photo Bogdan Kladnik

Slovenia

BRIDGES

- **Solkan Railway Bridge**
- Solkan, Soča River
- 1904 - 1906
- The world's largest stone arch on railway bridges
- Main arch span 85 m
- Technical monument

Text by Gorazd Humar

The Solkan railway bridge is the longest stone arch railway bridge in the world – the span of the main arch measures exactly 85 metres, while the total length of the bridge is 220 metres. The cut-stone main arch is made of 4,533 blocks of stone (limestone).

The Solkan Bridge was the key bridge structure on the second railway line connecting Vienna and Trieste, which was formally opened on 19 July 1906 by Archduke Franz Ferdinand, the heir to the Austrian throne.

The main arch of the bridge was built by the construction company Redlich und Berger of Vienna using shelly limestone from the quarry at Nabresina. Building 1,960 m^3 of stone blocks into the bridge's main arch took just 18 days. Following the removal of the wooden supporting stage, the stone arch sank just 6 millimetres under its own weight. The plans for the bridge were drawn up by the Austrian engineer Rudolf Jaussner, while construction was directed by the engineer Leopold Orley, whose work on this bridge won him great fame. A number of extremely demanding technical solutions were employed during construction of the bridge. Particularly notable were the technique of building a temporary central pier for the shuttering structure with a pneumatic foundation 9 metres below the surface of the water, and the fan-shaped wooden load-bearing structure of the shuttering itself.

On the night of 8-9 August 1916, during the Sixth Battle of the Isonzo, Austro-Hungarian forces withdrew to the left bank of the Soča (or Isonzo), destroying the main arch of the bridge behind them. Following the famous breakthrough near Kobarid (the Battle of Caporetto) in October 1917, the Austro-Hungarians erected a temporary steel structure of the Roth-Waagner type to bridge the gap where the main arch had stood (completed in May 1918).

At the end of 1918 the bridge passed under the control of the Italian state railway company, which rebuilt the bridge's main arch in stone between 1925 and 1927. The rebuilding was carried out by the Ragazzi engineering firm from Milan.

During the Second World War, the bridge was the target of six Allied bombing raids between 1944 and 1945. On 15 March 1945 a bomb struck the arch and pierced it, but the bridge did not collapse.

From 1945 to September 1947 the bridge was under the management of the Allied forces. Until June 1991 it was managed by the Yugoslav state railway company. Today the bridge is managed by Slovenia's state railway company Slovenske Železnice (SŽ). On 20 August 1985 the bridge was proclaimed a technical monument and today represents one of the greatest technical marvels of bridge-building in the world.

Solkan Railway Bridge

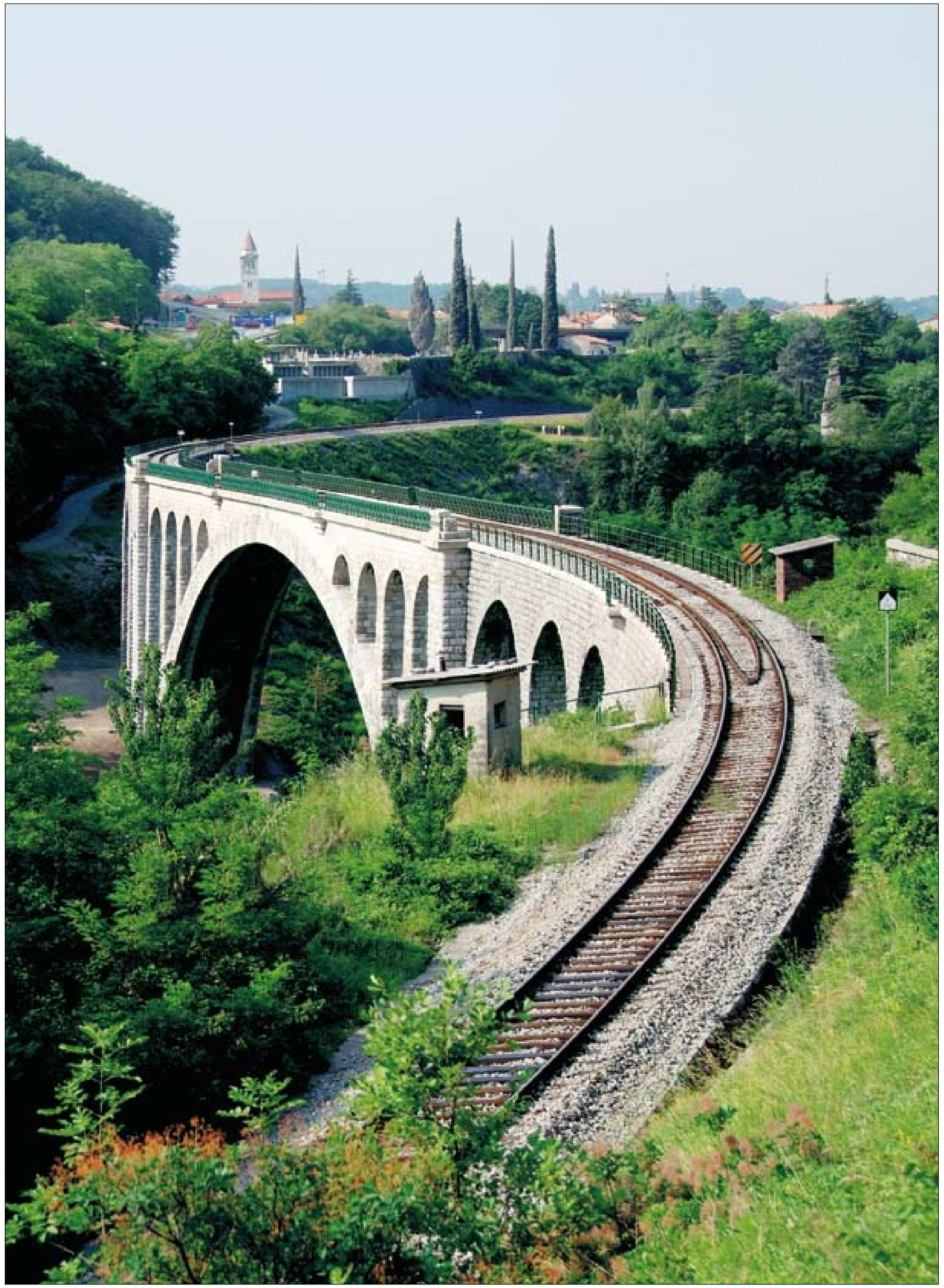


Photo Pavšič - Zavadlav, Slovenia

Solkan Railway Bridge

Photo Pavšič - Zavadlav, Slovenia

Slovenia

HYDROPOWER PLANTS

- **HPP Fala, Drava River**
- Fala
- 1913 - 1918
- The first Slovenian large hydropower plant
- Technical monument

Text by Branko Zadnik

The Drava River originates in the Toblaško polje in South Tyrol, Italy, and flows into Slovenia near Dravograd; after a 133-kilometre journey, it leaves Slovenia at Ormož.

Until 1918, when the Fala HPP began operation, the river’s flow along its entire length was unimpeded. From an area rich in forests, a lumber rafting transport route flowed down the river through Podravje and Podonavje and onwards towards the Black Sea. Prior to the construction of the railroad, the Drava River was the only (and later on, was the cheapest) transport route for lumber and other goods. In 1913, construction of the first hydroelectric power plant on the Drava River commenced, which was, at the same time, the largest hydroelectric power plant in the eastern Alpine region.

The Fala HPP was built in the Drava riverbed. It consisted of a powerhouse on the left embankment, five spillways and a navigation lock on the right embankment. A concession contract ordered the construction company to allow lumber rafts to travel via the power plant. Seven units were installed into the powerhouse. Once the entire chain of power plants along the section from Dravograd to Maribor was constructed, the need for increased capacity of the turbines of Fala HPP became evident. In order to remedy this, an additional unit was built between 1974 and 1977 so that the total turbine flow increased to more than 500 m^3/s, and net capacity to 48 MW.

With the development of modern transportation (railway), the navigation lock was no longer needed, for with the construction of the remaining power plants along the Drava River, lumber rafting died out. In 1987 the second renewal of Fala HPP began, encompassing the installation of two new units on right embankent, each with an output of 20 MW. All repair work was concluded by the middle of 1991, when the new units were put into operation.

With the conclusion of the renovation work, the era of the old units had come to an end, bringing them to a standstill forever. Today they represent something of a great value, a piece of the rich technical heritage of the first large Slovenian hydroelectric power plant. (Further reference: www.dem.si)

Slovenia

DAMS

- **Water Gate on the Ljubljanica**
- Ljubljana, on the River Ljubljanica
- 1933 - 1939
- Designed by architect Jože Plečnik
- Architectural monument

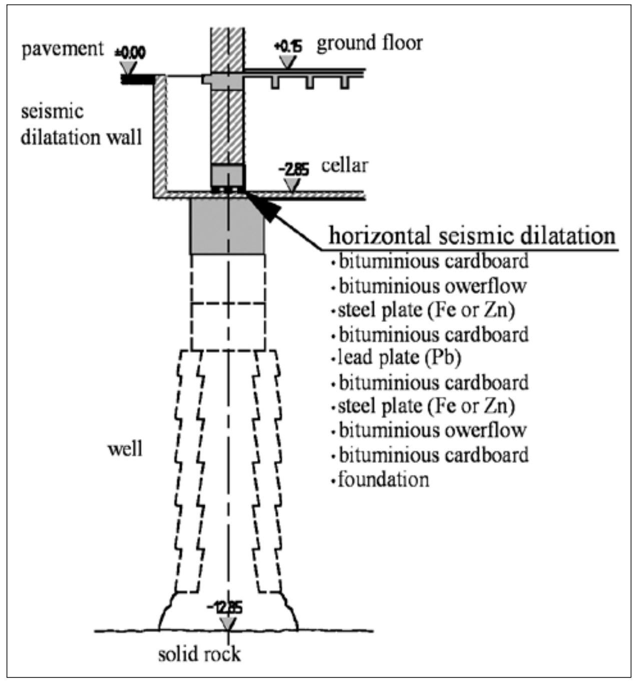
Text and photo by Gorazd Humar

The famous Slovene architect Jože Plečnik (1872–1957) was celebrated in Vienna and Prague, but his greatest fame was in his native Ljubljana, on which he set an indelible architectural seal. We might even go so far as to say that Jože Plečnik left such a mark on Ljubljana that it would be impossible to imagine the city without his key architectural creations. The simplicity, harmoniousness and beauty of his works have gained a dimension of universality and eternity. His interventions in the architecture of many important buildings (and bridges) in Ljubljana are still the subject of enormous admiration today. It is no wonder, then, that in his most fertile years he should have been entrusted with a great many other projects.

One such special commission was the construction of a new water gate on the River Ljubljanica just at the edge of the city centre. This project represented a special challenge for Jože Plečnik. His monumental Water Gate is conceived as a house on the water, with three towers. Between them Plečnik interwove a connecting bridge resting on Ionic columns, with sculpted heads based on Etruscan models set between the scrolls of their capitals. The upstream side of the Water Gate features a combination of Doric columns and Etruscan vases. The bridge linking the sections of the Water Gate ends in two monumental gateways reminiscent of the pylon gateways at the entrances to Egyptian temples.

The Water Gate is the most beautiful example of architectural design applied to a hydrotechnical structure in Slovenia, and probably one of the most beautiful structures of its kind in Europe.

Slovenia



BUILDINGS

- **Skyscraper of Ljubljana**
  (Ljubljanski nebotičnik)
- Ljubljana
- 1933
- Advanced structural design using seismic isolation
- At the time of its construction it was the ninth tallest building in Europe and the tallest in Slovenia

Text by Branko Zadnik

This prominent, tall, multipurpose building (flats, shops, offices), towering over its surroundings in the centre of Ljubljana, was built in 1933 and in terms of style is an example of modern Ljubljana architecture. At the time of its building it overstepped the boundaries of prescribed heights, established technical praxis and the concept of construction in Ljubljana. It represents the vertical dominant of a complex consisting of a tower, a block of flats and an arcade of shops, and the architect designed it holistically. Its appearance allowed it to transcend its cultural environment and become the symbol of a progressive city. Sixty metres tall and with six more storeys than any other building in the city, it was the tallest building in Slovenia and, at the time of building, the ninth tallest in Europe. People soon began referring to it affectionately as Nebotičnik (Skyscraper). The technical and other ideas that went into this building place it on a par with the greatest architectural feats in Europe and America. Its fittings were very modern for the time: express lifts, air conditioning, oil-fired central heating and other technical innovations, all of which enabled a high standard of living. This outstanding architectural monument is one of the sights of Ljubljana and a symbol of the city, as well as an essential element of the skyline.

Nebotičnik also boasts a very advanced structural design. The load-bearing structure on a ground plan measuring 19 x 19 metres is a 12-storey reinforced-concrete skeleton 60 metres tall, with intermediate walls of concrete and brick. This was an extraordinary technological achievement at the time. It is probably a coincidence that the construction permit for Nebotičnik was issued on16 April1931, 36 years, almost to the day, after Ljubljana was struck by a terrible earthquake (14 April 1895). This bitter event in Ljubljana's history was the reason for the incorporation of a new feature into the design of the new skyscraper: seismic isolation – a world first. The concept of seismic isolation for buildings was already known in professional circles around the world, but there is no evidence that it was ever actually used anywhere before Nebotičnik. The basic idea behind this solution is the sinking of deep foundations (wells) down to a solid rock basis on a horizon approximately 10 metres below the pavement of the basement. These wells are connected at the top by strip foundations which are separated from the solid basement walls by a horizontal earthquake trench of a thickness of approximately 16 mm. This is designed to allow horizontal differential movements (slips) of the upper part of the building's structure in relation to the foundations, and thus the absorption of seismic energy.

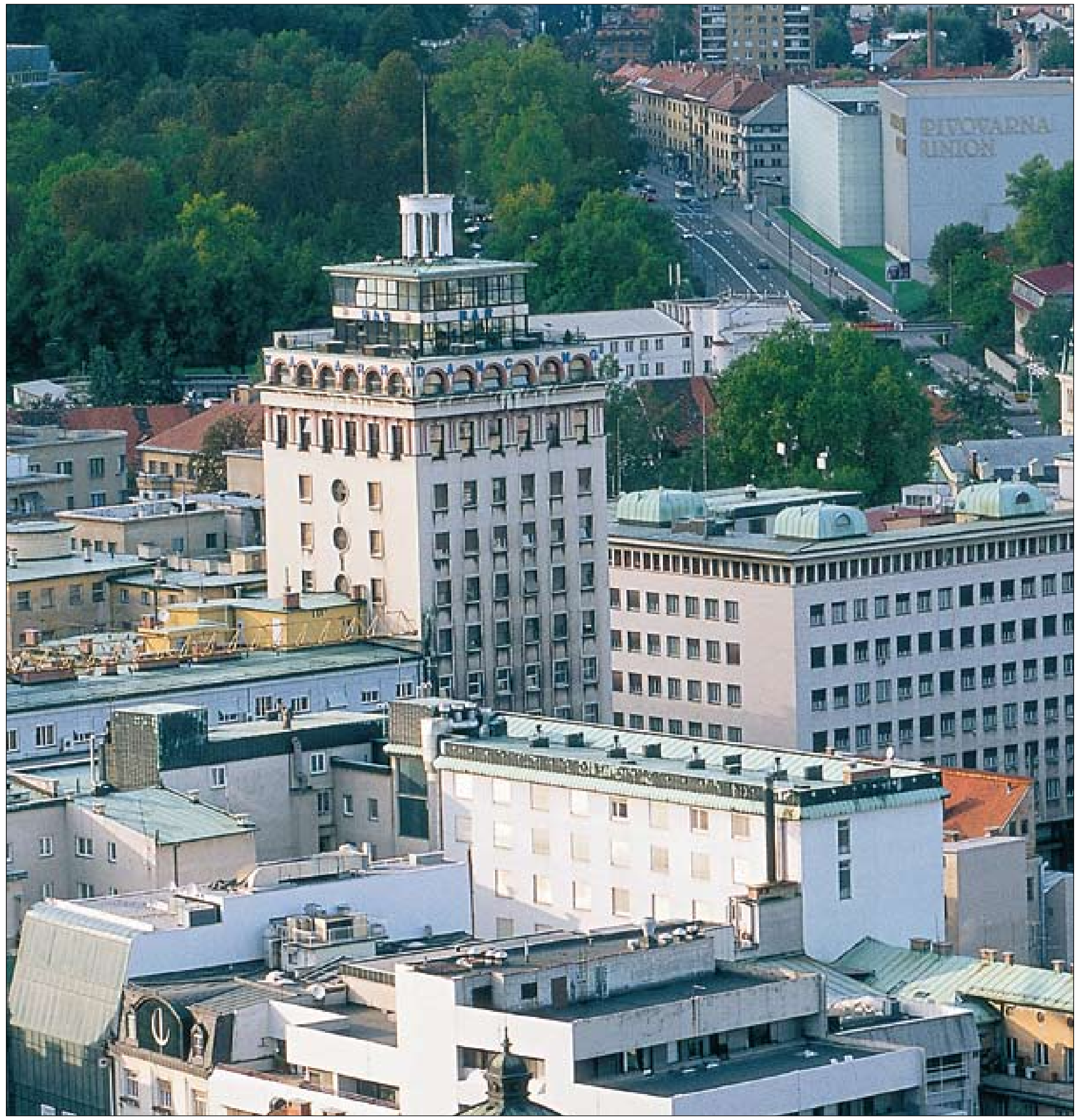
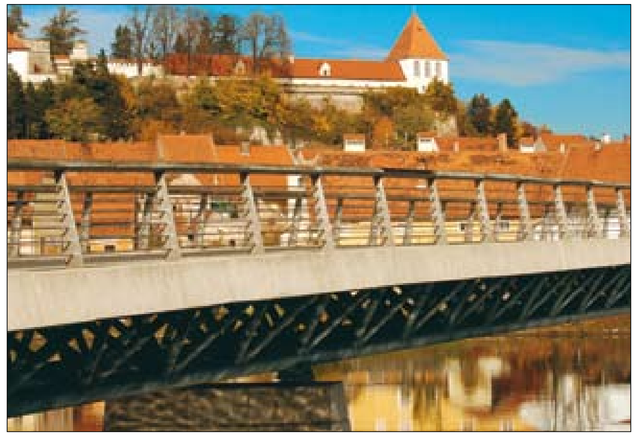


Photo Bogdan Kladnik

Slovenia



BRIDGES

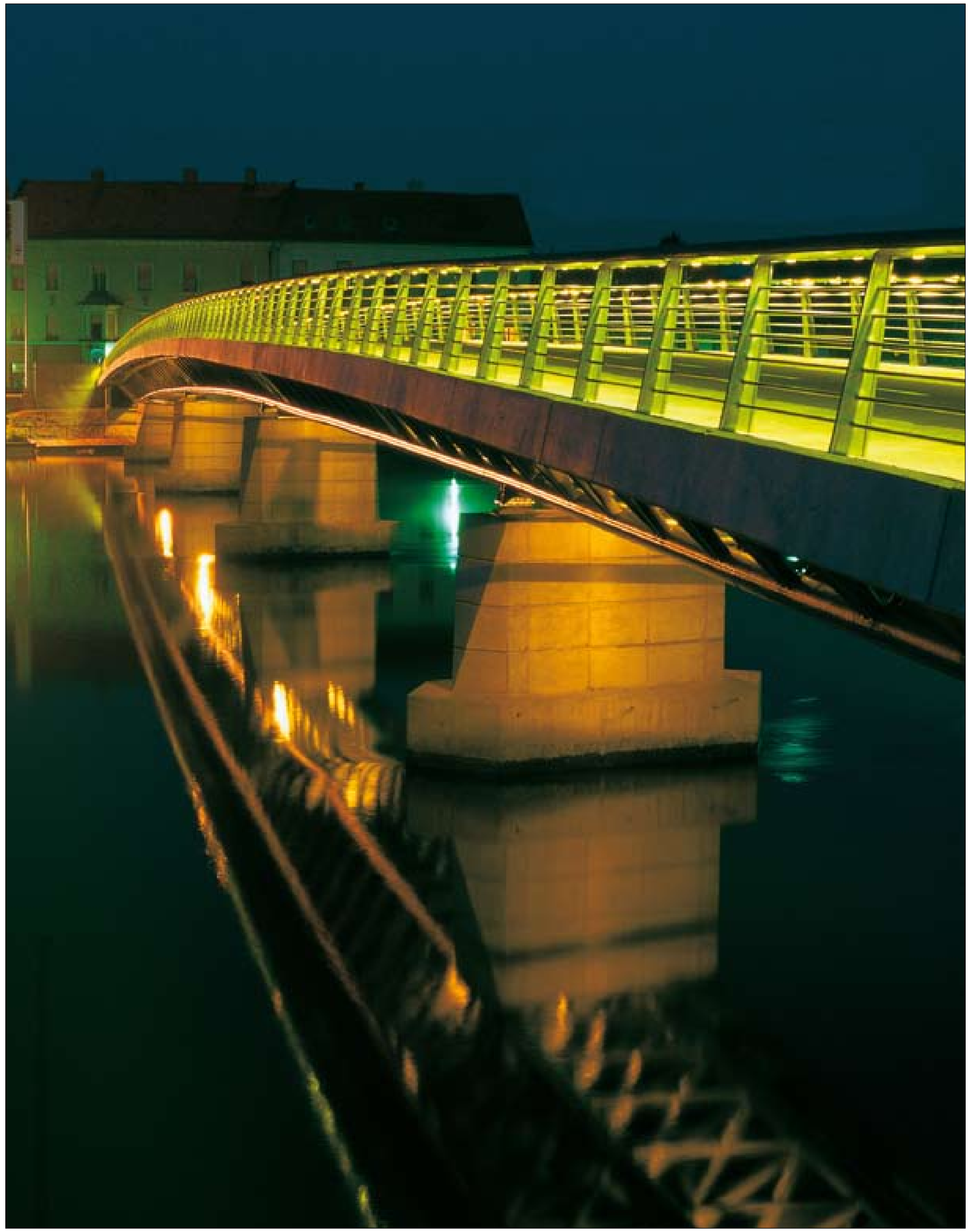
- **New pedestrian bridge**
- Ptuj, The Drava River
- 1997
- 154 m long steel structure
- EUROPEAN AWARD FOR STEEL STRUCTURES, London 1999, presented by ECCS (European Convention for Constructional Steelwork)

Text by Tanja Peteršič

The ancient town of Ptuj is located along the Drava River where the Panonic region extends most deeply into the pre-Alpine area of central Europe and where important bridges have been built since Roman times. In the Middle Ages, these ancient, monumental stone bridges, located near the Roman Castum Petovia, were replaced by wooden structures. These remainded until recently when they were destroyed by flood waters. After the World War II. they were replaced by concrete and steel bridges which followed the paths of new roads and railroads. The historical walk-ways, as well as the organic connection between the two river banks, where thus interrupted. To simulate the revitalisation of the old center, the local authorities of Ptuj decided to build the new bridge in order to reestablish the former trans-river connection.

The bridge connects the left bank of the Drava River with the Square on the right bank. Despite the fact that the new bridge is designed as a modern steel and concrete structure, its numerous elements drawn from history bring back memories of the wooden and steel constructions of the past.

The 154-metre open steel structure or the bridge rests on four riverbed and two bank supports, the geometry of which resembles the former wooden bridge supports. The steel structure is surfaced with thin concrete sheeting which ends in a sharp cornice bearing an open railing made of polished steel. The railing is topped with a wooden shelf which invites strollers to lean and admire the river and which houses small lamps that illuminate the surface of the bridge without denying the view of the night sky.



Owner: The Municipality of Ptuj
Design: Marjan Pipenbaher, Ponting d.o.o., Maribor
Contractors: SCT d.d., Ljubljana and Meteorit d.o.o., Hoče

Slovenia

BRIDGES

- **The 'Harp' Motorway Bridge in Ljubljana**
- Ljubljana
- 1999
- The first cable-stayed bridge in Slovenia

Ljubljana's Harp Bridge spans the Ljubljanica River, on the route of the ring road around Ljubljana. The Ljubljanica River flows through the old town centre and constitutes a kind of a linear city park lined by significant footpaths and cycle routes leading from the town to the green city hinterland. The bridge is low above the water and riverbanks, which is why the cable-stay construction with three pylons was used. It enables the formation of an extremely slim - just 38cm thick - bridge deck slab. It has also preserved the traversability of both riverbanks, thereby solving a complex ecological and urban design problem, while the vertically oriented bridge structure leaves its mark in the space as a relevant urban landmark. It calls drivers' attention to the crossing of a river and thus acts as a significant regional landmark. The structure of three parallel 'harps' is an attractive artistic element which changes its basic geometry in space according to the observer's motion. Since it is also a significant urban bridge, cycle and pedestrian paths were added, and its elements are formally more elaborate, possessing a touch of the nautical. The bridge with its pylons and wire cables evokes associations of a sailing ship, as it is exposed, like boats, to extreme weather conditions and corrosion. The bridge rails carry wide wooden bars, inviting pedestrians to view the river. Under the bars there are lamps which illuminate the pedestrian pathways, but preserve an unhampered view of the night sky. Next to the bridge there are steps incorporated into the environment, as well as park benches for resting and observing the structure.

Owner: DARS - Družba za avtoceste republike Slovenije
Engineer: DDC svetovanje inženiring,
Družba za svetovanje in inženiring, d.o.o.
Constructor: Vukašin Ačanski, Gradis-Biro za projektiranje/Design Bureau, Maribor
Architect: Peter Gabrijelčič, University of Ljubljana, Faculty of Architecture

Slovenia

BRIDGES

- **Črni Kal Viaduct** (Viadukt Črni Kal)
- Črni Kal, Ljubljana-Koper Highway
- 2001 - 2004
- Total length 1065 m
- 3 main spans of 140 m each

The prestressed concrete Črni Kal Viaduct is the key bridge structure on the Ljubljana–Koper motorway. The viaduct is located in a karst area, a sensitive landscape where every development has to be carefully considered. This was the principle that led the planner to adopt a cautious and subtle approach to the design of the main structure of this very large viaduct, which stands up to a hundred metres above the valley below. Since the viaduct describes a full quarter-circle over its total length of 1065 metres, the form of the piers is the element that gives the overall structure its slenderness, purity and environmentally friendly appearance. The tall Y-shaped piers are an elegant solution to the key architectonic problems and merge with the span structure to form a perfect monolith. The structural solution reveals the careful optimisation of the dimensions of the key elements of the viaduct, which is what gives the Črni Kal Viaduct its characteristic identity.

The foundations of the tallest piers of the viaduct are sunk in elliptical wells (14.5 x 12.0 m) up to 21 metres deep. The piers were built using self-climbing formwork, while the main span structure was built using free cantilever construction with spans of up to 140 metres. One special feature of the viaduct is the 3-metre-high windbreak to protect vehicles from powerful gusts of wind that can reach speeds of up to 180 km/h. A test of the effectiveness of the windbreak using diffusers was carried out in a wind tunnel.

The viaduct is equipped with automatic ice and wind speed alarms. The structure has been designed to last for 120 years.

Owner: DARS - Družba za avtoceste republike Slovenije
Engineer: DDC svetovanje inženiring,
Družba za svetovanje in inženiring, d.o.o.
Designer: Marjan Pipenbaher, Ponting d.o.o.
Consulting architect: Janez Koželj
Contractor: J.V. Črni Kal, a joint venture of:
SCT d.d., Ljubljana and Primorje d.d., Ajdovščina

Slovenia

BRIDGES

- **Puch Bridge** (Puhov most na Ptuju)
- Ptuj, over the Drava River
- 18 May 2007
- Awarded by IZS - Slovenian Chamber of Engineers, 2007
- Innovative extra-dosed bridge construction

Text by Gorazd Humar

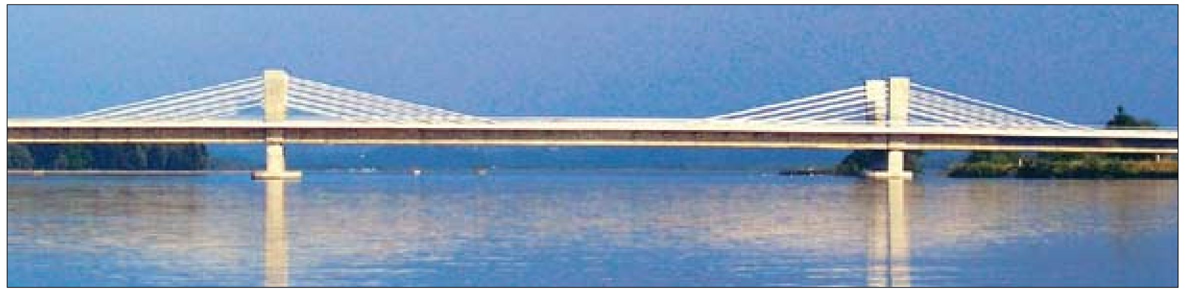
Ptuj is the oldest town in Slovenia, because an important Roman province (Petovia) was situated at this place as long as two thousand years ago. The first bridge for access to the town was built by the Romans. The bridge was not preserved until today because it was made of wood. During the centuries the town of Ptuj experienced vast development. In the immediate surroundings of Ptuj numerous bridges were built because of the important routes which led past the town. In 1959 the first bridge in Slovenia was built over the Drava using free cantilever construction. The pre-stressed bridge, with a main span of 79 meters, was designed by the engineer B. Pipan. At the time this bridge was one of the biggest worldwide built according to the system of free cantilever construction.

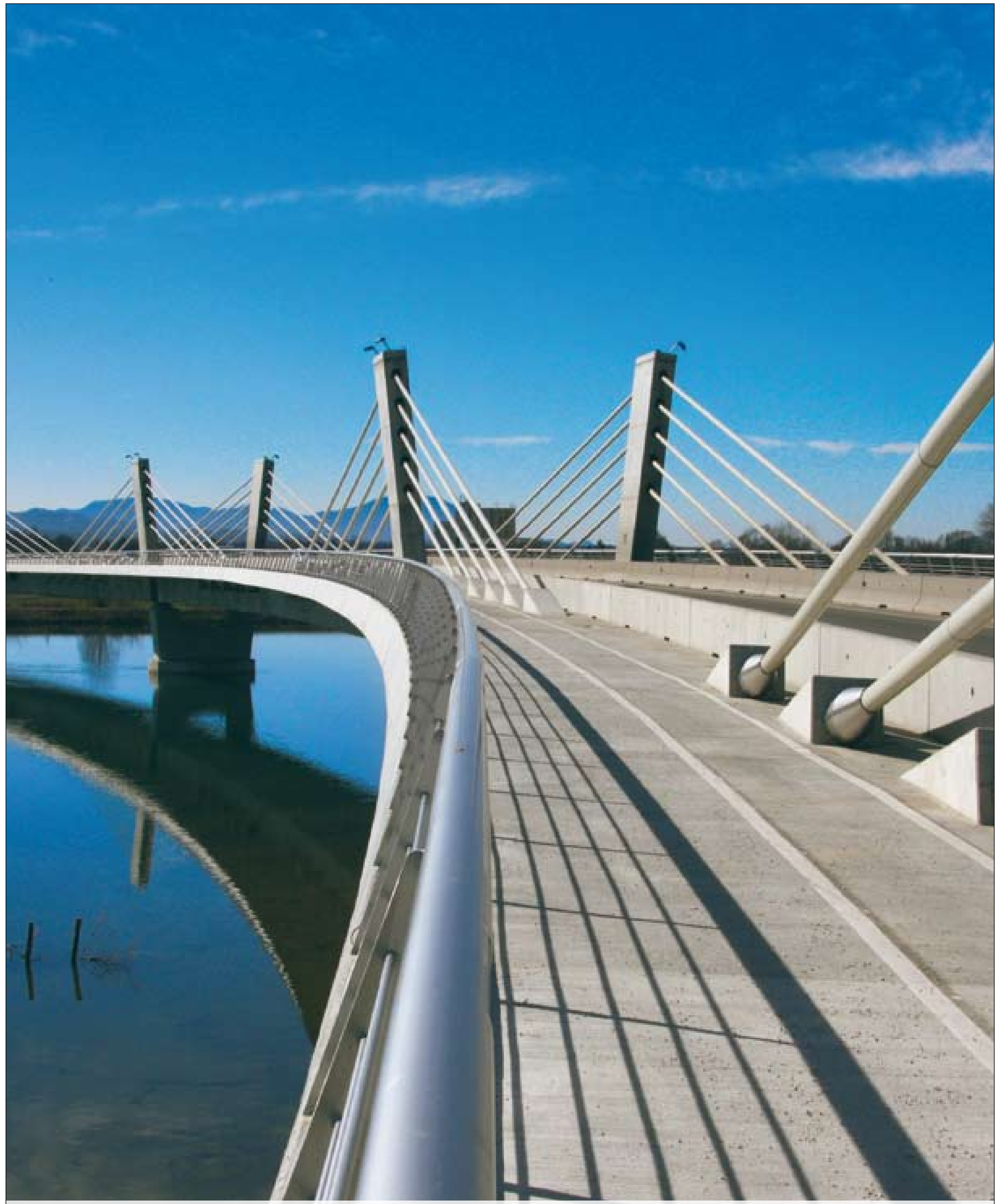
The picturesque scenery of the ancient town of Ptuj with its surroundings set particular requirements to the designers of new bridges. Therefore, the placement of each new bridge presented a very difficult task. The designer Viktor Markelj was also aware of that when he was preparing the perfect solution for the new road bridge near Ptuj. After winning the public anonymous design Competition for the conceptual solution for the bridge in 2004, the project for the new bridge also reached the realisation stage. This was the first very successfully performed construction of a bridge with inclined cables and low pilons (extra-dosed bridge) in Slovenia. For the first time the solution of a bridge supported by inclined cables in a sharp horizontal curve with the radius r = 460 meters and the length of the bridge l = 430 meters was used. The superstructure of the bridge is a continuous externally pre-stressed reinforced concrete box with distinctive inclined cables and static spans: 65 + 100 +100 +100 + 65 = 430 m.

The static height of the main span hollow box structure is only 2.70 meters, which can be attributed to the use of external pre-stressed cables. The elegance of the crossing of the Drava in the sharp horizontal curve where the bridge is situated was conditioned by the access road and can be attributed to the successfully applied symbiosis of inclined cables and external pre-stressing.

The advanced and innovative technological solution of the Puch Bridge can also be seen in the design of the facility, with particular construction stages with temporary support of the structure using the cantilever method and comprehensive camber elements, original pillar details, cable deviators and anchorage points.

Successfully implemented technical solutions also brought important new solutions and freshness in the application of extra-dosed bridges worldwide.





Designer: Viktor Markelj, Ponting d.o.o., Maribor
Cooperating architect: Peter Gabrijelčič
Investor: DARS d.d., Celje
Contractors: JV SCT d.d., Ljubljana and PORR a.g., Vienna
Time of construction: Oct. 2005 – May 2007

Puch Bridge in Ptuj

Slovenia

BRIDGES

- **Studenci Footbridge**
- Maribor, over the Drava River
- 2007
- Footbridge Award 2008

Text by Viktor Markelj

The Studenci Footbridge over the Drava River in Maribor is an example of a successfully performed reconstruction of an old bridge with the design of a new, technically freshly designed structure in a thoughtful steel truss design. It is characterised by an extraordinary transparency and light appearance, achieved with a relatively simple structural solution which, with its clever design, virtually creates an extremely elegant footbridge which optically reminds one more of a shallow arch structure rather than a dull latticed load-bearing structure of a bridge. A successful optical illusion is performed with the use of a skillfully designed fence and bridge deck which are slightly curved, whereas the main load-bearing space truss does not change its height and dimensions through the entire length of the bridge. This partly disguised sunken load-bearing part of the bridge gives the entire footbridge charm and elegance. A successful combination of the load-bearing steel structure of the bridge with the deck area made of wood thus shows the design trend of footbridges with long spans. The Studenci Footbridge for pedestrians and cyclists is illuminated with aesthetic and energy saving LED lamps, which illuminate the bridge throughout its whole length from below the fence and give it an interesting nocturnal contour. The set power of all the lamps together is only 350 W. This was also an optimal solution for the investor, the Municipality of Maribor, because of their favorable prices (1.2 m EUR in 2007).

The main structure of the bridge, steel tubes with the weight of 93,000 kg and length of 126 meters, is made of three equal spans each with a length of 42 m. The clear width is 3.20 meters in the middle of the bridge, although the bridge gradually extends towards the piles to a width of 5.80 meters. The deck area of the bridge is made of boards with the thickness of 44 mm from the hard tropical wood bangkirai.

The bridge was awarded the important Footbridge Award 2008 in Porto in Portugal in the technical medium span category, which is given every three years by the worldwide leading bridge magazine Bridge Design & Engineering from London.

Designer: Viktor Markelj, Ponting d.o.o., Maribor
Cooperating architect: Reichenberg arhitektura d.o.o., Maribor
Investor: The Municipality of Maribor
Contractors: The POMGRAD group, Konstruktor NGR d.d., Hoče
Steel structure: Meteroit d.o.o., Hoče
Time of construction: Jan. 2007 – Dec. 2007

Studenci Footbridge, Maribor

Spain

CANALS

- **Castille Canal**
- Palencia and Valladolid
- 1753 - 1849
- One of the most important engineering works in Spain

A water channel was built between 1753 and 1849 to transport grain and other goods from the interior of Castille to the northern ports of Spain. The major project intended to connect Segovia with Santander by river, but only 207 km were built on the lands of Palencia and Valladolid, through the arid Castille. The ends have an elevation difference of only 150 m.

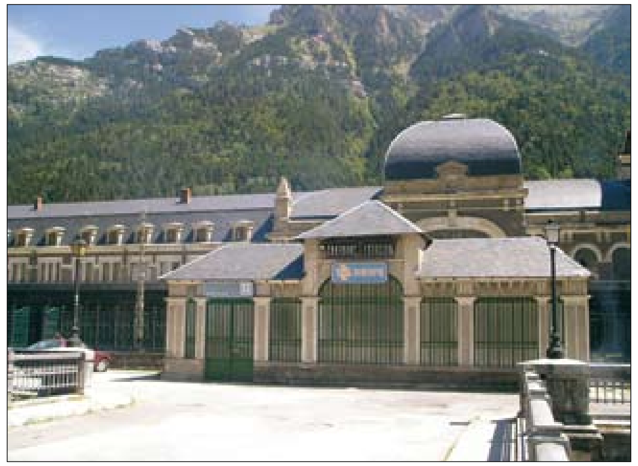
This canal is one of the most important engineering works in the history of Spain, commissioned by Antonio de Ulloa. In addition to the water channel, with a trapezoidal cross-section between 11 and 22 m wide and between 1.80 and 3 m deep, many other works were built: dams and aqueducts, locks (oval or rectangular) lowering ships up to 15 m, docks of up to 330 x 50 m which allowed loading and unloading, mills, flour mills and warehouses, all masonry buildings. During its most active years of service, more than 400 barges were towed by horses up the channel to Santander. The arrival of the railroad in 1959, after one hundred years of service, converted this canal into an irrigation channel for 60,000 hectares of land. In its current use, water is supplied to urban and rural areas. It has become a tourist attraction and has been environmentally protected as a green corridor through brownish Castille.

Carlos Lemaur, Antonio de Ulloa

Spain

BUILDINGS

- **Canfranc International Railway Station**
- Canfranc, Huesca
- 1925
- Largest train station in Spain



The largest train station in Spain, and one of the most spectacular in Europe, was designed as a great showcase for Spain to impress foreign visitors. Its construction, part of the proposed creation of a railroad connection along the Pyrenees from Spain to France through the Somport Tunnel, began in 1915, ending in 1925. It was opened to service in 1928 by King Alfonso XIII and the President of the French Republic, G. Doumergue.

The station is one of the most important historic buildings in Spain and was declared a 'site of cultural interest' in 2002. This Modern railway station housed a luxury hotel, casino, customs agency, a branch of the Bank of Spain, a canteen and nursing facility, all in a huge three-storey structure, 240 meters long, with 75 accesses each side and bilingual signage. The passenger building's longitudinal symmetrical structure, in addition to its three storeys, accentuated in height at its ends and centre, is decorated with large windows, pilasters and Art Deco woodwork, all combining to create a sumptuous space.

The exterior refers to nineteenth century French palace architecture, with a variety of wall surfaces: concrete, stone, iron and glass, which creates an interesting chromatic interplay accentuated by the presence of four slate-covered slopes. The two floors of the body open to the area of the track through a half-point arched metal canopy on columns. The interior is bright, balanced and elegant, with a functional distribution of space from a central lobby roofed with a large cast iron dome. Side galleries accommodate the customs post, police station, post office and an international hotel company.

Rail service was suspended between 1936 and 1945 due to the Spanish Civil War and World War II. Since its decommissioning in 1970 upon the failure of L'Estanguet Bridge, the station fell into neglect. In the mid-90s came the first attempts at rehabilitation, now mired in controversy.

Guillermo Brockmann (Spain) and Le Cornee (France)

Spain

BUILDINGS

- **Zarzuela Hippodrome Roof**
- Madrid
- 1935
- Torroja - the titan of reinforced concrete

This is one of the best known structures of the great engineer Eduardo Torroja, who with Eugene Freyssinet and Le Corbusier was considered a 'titan" of reinforced concrete and a precasting pioneer. This work still impresses the foreign technical specialists who visit it. Torroja, besides being an extraordinary technician, intuitively knew how to design effective structures.

The roof of the Zarzuela Hippodrome is a laminar structure with a 12.60 m span, composed of a combination of horizontal axis hyperboloids supported by pillars every 5 m. These spans are cable-stayed to the roof, which extends out in the opposite direction providing the necessary counterweight to the main cantilevered roof surface. The thickness of the roof at its edge is only 5 cm, increasing to 15 cm at the column line. The roof was damaged in 25 places during Spanish Civil War bombings, but the damage was relatively minor and 70 years later the roof continues in full service.

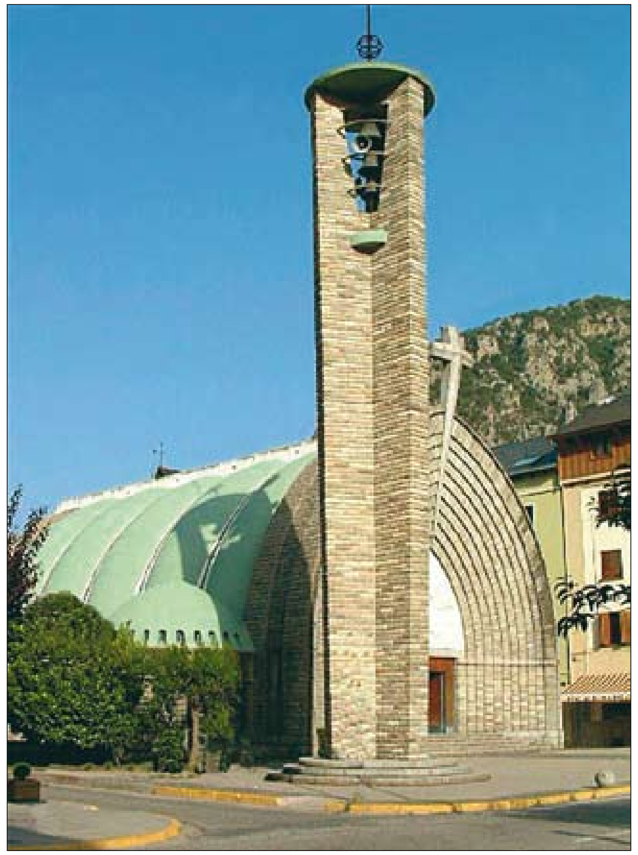
One of the fundamental contributions of Eduardo Torroja to the history of civil engineering was to design and implement new construction processes with the intent of promoting quality improvement based on a large scientific body of knowledge, both of materials and techniques.

Eduardo Torroja Miret

Spain

RELIGIOUS BUILDINGS

- **Pont de Suert Church**
- Pont de Suert, Lleida
- 1952
- Lobes - like sea shells



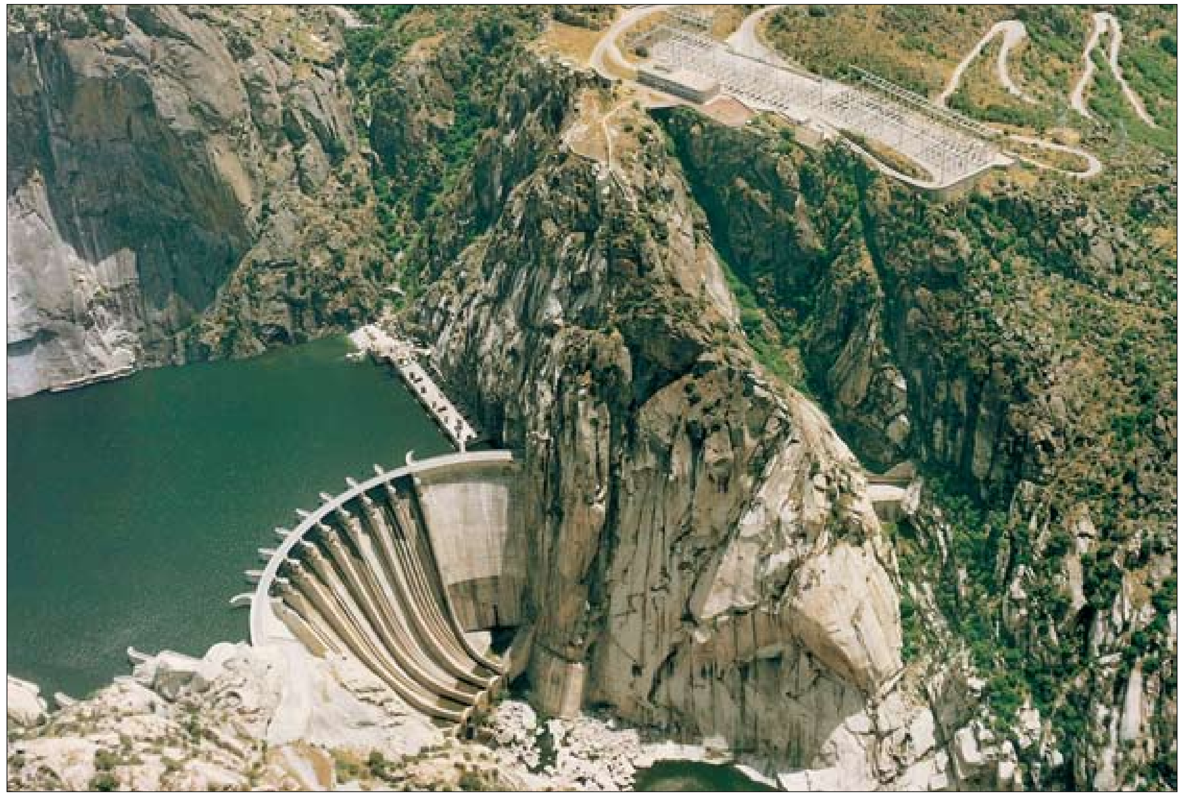
The simple Pont de Suert Church consists of a single rectangular body vaulted with laminar ogival equilateral domes, which can be seen perfectly from both the inside and the outside, stiffened by a reinforced concrete ridge.

The vaults are formed by three layers of hollow brick to prevent buckling. The first layer is joined with plaster to serve as formwork. The other two were mortar cemented reinforced with steel. This cost-effective building solution adapts to any desired shape, even changing its curvature. All its stress resistance derives from the set of thin layers. In between the vaults, adjacent triangular panelled lobes prevent the vault's buckling and at the same time allowing natural light to enter the hall through glass tiles. The shape of the lobes resembles seashells. Half-ellipsoidal niches provide an enormous sense of lightness and thinness at the base of the walls.

Near the entrance to the left, a circular baptistery was built. It also contains a beautiful chapel with a pointed dome in the form of acorns.

Eduardo Torroja Miret, Rodriguez Mijares

Spain



DAMS

- **Aldeadávila de la Rivera, Salamanca**
- Feligresía de Bruço
  River Duero/Douro
- 1963
- Height of the dam 140 m

At the time of its construction, it became the largest hydropower facility in Western Europe, with an average 2440 GWh power generation per year, with six groups of 120.00 Mw turbine generators each. The total power installed in the Douro River hydropower facility was 7,600 GWh.

This dam was built on high-quality granite over the canyon of the Douro River, a breathtaking feature of exceptional beauty. The design of the dam is spectacular, especially the lined chute spillway. As the spillway discharge capacity is 10,000 m^3/s and the length of the chute is only 50 m, a volume of 200 m^3/m is achieved. Quite a figure.

This dump arch gravity dam has a total top length of 250 m and is 140 m high. The spillway consists of eight 14 m gates, 7.85 m high. Other significant elements of the project are a tunnel outlet valve for 2800 m^3/s, two outlet tunnel galleries with a 137 m^2 section and 4,250 m^2 surge tanks, and a 5 m diameter circular instrumentation well 318 m deep. The power plant underground cavern required a 52 m high and 140 m long excavation for its placement.

Project Director: Pedro Martínez Artola

Spain

DAMS

- **Susqueda Dam**
- Girona, Cataluña
- 1967
- Height of the dam 135 m

Susqueda Dam came into service in 1967, regulating the inflows of the Ter River, limiting the flow circulating through Girona and supplying water to the whole region of Barcelona. In addition, it produces electricity through an underground power plant with 86.3 MW of power generation installed, achieving peak energy production of 180 GWh.

This double-curvature arch dam, 135 m high, blends perfectly with the environment, creating a beautiful feature now often visited. The abutments have been hollowed, both the right and the left supported by semi-hollow hyperbolic columns and a helical staircase that confers marked originality. The dam is equipped with eight maintenance and structure control galleries. The maximum angle of aperture arc is 97°24'. It is composed of 34 vertical blocks, 14 m wide. The spillway is located at the arch's centre, consisting of seven lined chutes with a total length of 121 m, allowing an outlet of 2,800 m^3/s. The outlet systems are completed by four deep-outlet 200 m^3/s Howell Bunger valves. Being a water supply system, the dam's two towers, 100 m high and 12 m in diameter, have intakes at different levels of the reservoir in order to obtain the best water quality available.

Project designer: A. Rebollo

Spain

BRIDGES

- **Centennial Bridge**
- Sevile, Spain
- 1992
- A milestone in the progress of long-span precast bridges

On the occasion of the Universal Exposition in Seville in 1992, this bridge was built over the Alfonso XIII pier of the Guadalquivir River. The bridge is considered a milestone in the progress of long-span precast bridges. A competition was held for the bridge design, which required a monumental effort combining its urban utility with its traffic needs. The use of a precast solution does not mar the quality of the aesthetics achieved, as it depends only on the design, not on the construction process.

The total length of the bridge is 2027 m, 565 m of which represent the central span and 1462 m cable-stayed isostatic accesses, with spans between 42 and 46 m. The two central pillars are 105 m high, and made of reinforced white concrete and weathering steel. The deck is 22 m wide and was built using more than 90% prefabricated elements, which permitted its erection at a height of 50 m without interfering in the river's navigation. The deck's progress throughout construction was 48 m per week.

Jose Antonio Fernandez Ordonez, Julio Marinez Calzón, Millanes Francisco Guillermo Ontañón, Manuel Burón and Javier Marco (ICCP)

Spain

TOWERS

- **Collserola Tower**
- Barcelona
- 1992
- 288 m-high telecommunications tower

This telecommunications tower, 288 m high, was built in the mountains of Tibidabo for the Barcelona Olympics in 1992. The construction project was developed by civil engineers from the original design by Norman Foster, winner of the competition, and combined the creativity and spectacle of the architectural solution with an elegant approach to the construction process. The tower was a state-of-the-art innovation in the field of tall buildings in that it brought up new technological possibilities for the use of new composite materials.

The structure is composed of five structural subsystems:

- core interior ring of concrete, 205 m high, inside diameter 3 m and height-variable thickness from 75 to 30 cm
- structure of metal, composed of 13 platforms in curvilinear equilateral triangles
- Prestressed metal tension members
- Tension bars of mixed organic fibre which stay the metal body to the shaft
- Metal mast 82 m high, with a tubular section in the first 60 m and prismatic lattice in the rest

Julio Calzón Martinez and Manuel Juliá Vilardell

Spain

BRIDGES

- **La Regenta Arch Bridge**
- Asturias
- 1996
- Arch span of 194 m

The most important structural element of the Cantabrian Highway in the west of Asturias is the La Regenta viaduct, 381.6 m. long, which crosses the Cabo River with an arch 194 m long and 50.37 m high. Juan José Arenas de Pablo was awarded the International Puente de Alcantara Award for the bridge in 1996.

The design of the bridge fits perfectly into the valley and with the geometry of the bridges on the old road. The height above the valley floor is 105 m. It is an arch bridge supported by ten massive 6.5 m-wide pillars, which, along with ten others outside the arch's axis, support the 12 m-wide deck section with steel caissons 6.50 m wide and 1.40 m thick. The arch is made of a reinforced concrete hollow section, 10.50 m wide and variable thickness between 2.40 and 4.20 m, built by a novel process consisting of an articulated free triangulated cantilever launch, temporarily supported by prestressing straps. This section has high mechanical performance. The extreme 52 m pillars result in a slim and flexible structure, enough to minimize the stresses due to the secondary effects produced by the deck's thermal shrinkage and concrete deterioration.

Jose Juan Pablo Arenas, et al.

Spain

BUILDINGS

- **Euskalduna Palace of Congresses and Music**
- Bilbao
- 1999
- World's Best Conference Centre 2003

Located near the estuary of Bilbao's Nalón River, where its industrial and port facilities have been converted into such unique buildings as the Guggenheim Museum and Abandoibarra, and 53,000 m^2 of cultural land development, this project was granted the 2003 Apex Award for the 'World's Best Conference Centre' by the International Association of Congress Centres and the 2001 Prix Enric Miralles at the Sixth Biennial of Spanish Architecture. This singular building was designed to resemble a vessel under construction surrounded by scaffolding, emerging from the dry dock located in the Euskalduna yard.

In addition to the grandeur of the building (156x124x52 m), its most unique aspect is its resemblance to a vessel, in both its design and its construction. The 'vessel' is a block 90 m long, 40 m high and 52 m wide, pierced only by the entrances to the interior spaces: chambers (conferences, meetings and trials) are at the keel's base, the auditorium (2,200 seats) over the chambers and the scenic cache (2,000 m^2) in the ship's 'stern'. Surrounding the ship a scaffolding framework, housing the multipurpose hall (2,000 m^2), lookouts, elevators, escalators and ramps at various levels, achieves a similar effect to the fabric of platforms and stairs of a shipyard.

The building was built like a ship: the 'frames' or ribs of the hull (inverted 'U' porticos) support the 'riding' (reinforced concrete blocks), which were stayed (here with metal latticework and concrete slabs) and built on different 'decks'. Over this, the boat was covered with a double plate (here a sandwich-panel curtain wall) with an interior space (2 m) that separates it from the hull extension (fabric), which makes it noise-isolated and also houses the piping for the building's services.

Engineers: F. Soriano, E. Sanus, and G. Candela

Spain

HARBOURS

- **Bilbao Harbour**
- Bilbao
- 1898 - 1998
- A world reference in port works

The construction of the Port of Bilbao is a world reference in port works and an example of the ability of Spanish civil engineers. The sea batters this port hard and often, validating the theoretical calculations, but the result has always meant a huge advance in knowledge.

The first expansion was completed in 1903:

- Santurce Breakwater (E. Churruca) (1,450 m), wrecked in 1894 (in 1965 it was reinforced with 60-ton blocks)
- Algorta Seawall (1,150 m)

The second expansion (F. Rodriguez Perez):

- Dock Punta Lucero (2,000 m), temporarily reinforced in 1976 with 85-ton blocks and finally in 1985 with a new cross-section and 150-ton blocks

The third and final expansion (J. Uzcanga, EJ Villanueva and M. Santos) was finished in 1998:

- Zierbena pier (2,500 m) with 100-ton blocks
- Exterior Santurce Seawall (1,300 m)

The total length of the breakwater structures in this port are approximately 8 km. Its depth ranges between 17 and 35 m, and the weight of the blocks on the outer layers varies from 60 to 150 tons. Despite the fact that the sea has tested (especially in 1976 and 1996) the true power of the works, happily the structures have been fulfilling the role for which they were planned.

Bilbao Harbour

Spain

BRIDGES

- **Bridge over the Ebro River on the AVE Madrid - Barcelona line**
- Zaragoza
- 2002
- Maximum noise-dampening solution

The crossing of the high-speed Madrid - Barcelona railway line over the Ebro River is a novel bridge of continuous prestressed light concrete with a 120 m main span Vierendeel truss with upper and lateral streamlining, resembling a large prestressed concrete latticework – a unique bridge for the crossing of the most advanced railway service over the largest river in Spain. This proposal presented the best solution for maximum noise dampening along the environmentally protected riverbanks. The Vierendel structure is stiffer than a hypothetical interior triangular beam. This was the challenge: simplify the design to be able to build it in concrete.

The total length of the bridge over the riverbed is 546 m. The great Vierendeel truss has a total depth of 9.15 m. The cross section has a trapezoidal shape. In the upper part it has a maximum width of 16.56 m, while at the bottom it reaches 12.90 m. The webs have circular voids 3.80 m in diameter placed every 6.0 m. It has a set of transverse beams with a circular elevation every 3.0 m with a trapezoidal cross section whose thickness ranges from 0.50 to 0.60 m. As the deck's longitudinal section is not uniform, its behaviour is clearly three-dimensional, which made the use of finite element analysis indispensable. The construction process used incremental launching from both abutments. The segmented ribs have lengths ranging between 12 and 18 m. The cross-rib beams were prestressed in the precast yard, while the segments were post-tensioned once the deck had been pushed.

Project designers: Javier Manterola Armisén, Antonio Martínez-Cutillas, Miguel Angel Gil Ginés

Spain

TUNNELS

- **Guadarrama Tunnel**
- Madrid - Segovia
- 2002 - 2005
- Use of four double-shield TBMs

The cornerstone of the new high-speed Spanish railway line (AVE) Madrid - Valladolid, this 28.4 km double tunnel, (30 m between axes) was drilled under the Sierra de Guadarrama through igneous and metamorphic rock. The commitment to minimum environmental impact led to the use of four double-shield TBMs with a diameter of 9.46 m. The tunnel's structure consists of precast, fire-retardant, treated concrete, 7 - section rings, with an 8.50 m inner diameter and 32 cm thick. Four million cubic meters of rock were excavated and 248,500 sections in 35,500 rings were placed as a coating.

As a highlight of the safety aspects of the tunnel, we can point to its 2022 m of evacuation galleries connected to the tunnel every 250 m (every 50 m in the emergency space), its 1.70 m-wide lateral evacuation platform along the entire tunnel, an emergency space 500 meters long, two energy-independent control centres with 4 days of autonomy, permanent lighting, axle load detection, SOS posts and public address speakers every 40 m. All major Spanish contractors contributed in various joint ventures to this project.

Project Director: José Antonio Cobreros Aranguren

Spain

City of Arts and Sciences

The City of Arts and Sciences is the amazing transformation of the Turia River's old riverbed into an avant-garde 350,000 m^2 recreational area to become the largest cultural development of its kind in Europe. It is a complex of sculptural buildings, white and monumental, surrounded by greenery, lakes, roads and walkways.

The five major areas in the complex are:

BUILDINGS

- **City of Arts and Sciences**
- Valencia
- 1998 - 2004

L'Hemisfèric (1998)

Occupying an area of 200x1300 m, from two ponds emerge a giant shell composed of an ovoidal deck area and some lateral moving elements (shade structures and gates) that build up to a transparent space resembling a huge eye opening to the world.

Science Museum Príncipe Felipe (2000)

The building is an architectural milestone, occupying 30,000 m^2 for interactive exhibits on the evolution of life, science and technology.

L'Umbracle (2000)

A promenade sculpture garden under a veranda and original structure of fixed and floating arcs, resembling covering branches.

Oceanographic (2003)

A circular combination of ten different glass-walled buildings. Presently, is the largest aquarium in Europe and the third in the world.

Palau de les Arts Reina Sofia (2004)

This 37,000 m^2 building houses four auditoriums for 4,000 people. It resembles a great ovoidal sculpture. The decks, or 'feathers', are 230 m long and 70 m high. The two 'shells' which hug the building's exterior are built of steel sheet with ceramic tiling. It has cantilever platforms at different heights with walkways and gardens, offering a beautiful contrast between the opaque 'carcass' and transparent glass housings.

Santiago Calatrava and Felix Candela

Spain

HIGHWAYS and ROADS

- **Cantabrian Motorway**
- Basque Country, Cantabria, Asturias and Galicia
- 1995 - 2008
- 486 km dual motorway

Since the Paleolithic, the Cantabrian region has had difficult connections with Spain and the rest of Europe. The Cantabrian Highway (European road E-70) is a dual 486 km motorway that travels along the coast of the Bay of Biscay. It begins in Bilbao, travelling through Santander (Cantabria), Llanes, Gijon and Aviles (Asturias) and entering Galicia through Ribadeo, ending in Baamonde, where it connects with the A-6 Highway (Madrid - A Coruña). It also connects with France through the AP-8 tollroad, which follows with Bilbao Irun and Hendaye, 119 km, completed in 1973.

It is the great cornerstone of the Cantabrian 'corniche'. This territory encompasses four Spanish regions, populated by 6.5 million inhabitants, half of them living in urbanised industrial cities (17.2% of the Spanish population), in an area of 53,000 km² (10%), with 728 municipalities, 23 of which have more than 50,000 inhabitants, adding nearly 3 million.

The construction of this free highway has induced the most significant process of change in these territories since the Middle Ages, socio-culturally and economically. The works have progressed since 1995 through complicated terrain, east to west, and only small sections remain under construction, especially in Galicia, which are expected to be completed by 2010.

Turkey

THE GREAT ARCHITECT SINAN (1490-1588)

The great architect Sinan is a phenomenal figure in the history of architecture and engineering. His name is strongly representative of the glory of the Ottoman Empire during the 16th century, reflecting the brilliance of the Ottoman Golden Age during the powerful reign of Suleiman the Magnificent. The fact that a great emperor and a master builder lived in the same period and that their genius was profoundly interconnected constituted a real chance for the development of the structural art at a universal level.

Sinan was born in a small village named Agirnas (Kayseri) in Central Anatolia in 1490 and adopted by the state authorities as a talented young boy to attend janissary schools (1512) and finally as a young military engineer participating in the conquest of various neighbouring regions of Anatolia. He played an authoritative role in the wars on a technical scale in his position as military chief engineer (1514-1530). He was appointed Head Architect of the Empire in 1538.

The imperial function of the Head Architect corresponded, quite likely, to the post of minister of public works in our contemporary understanding. During the initial period of ten years in this role, Sinan accomplished, besides a number of civil works and buildings in the capital city of Istanbul, the design several mosques that constituted works of prestige both architecturally and socially, and a series of complexes that included worship units, high schools and university level schools, and social welfare facilities. The names of imperial family members were given to such urban complexes. In later years, the names of notable vezirs (ministers) and especially sadrazams (prime ministers) were given to such urban structures, as well as to viaducts, aqueducts and water networks.

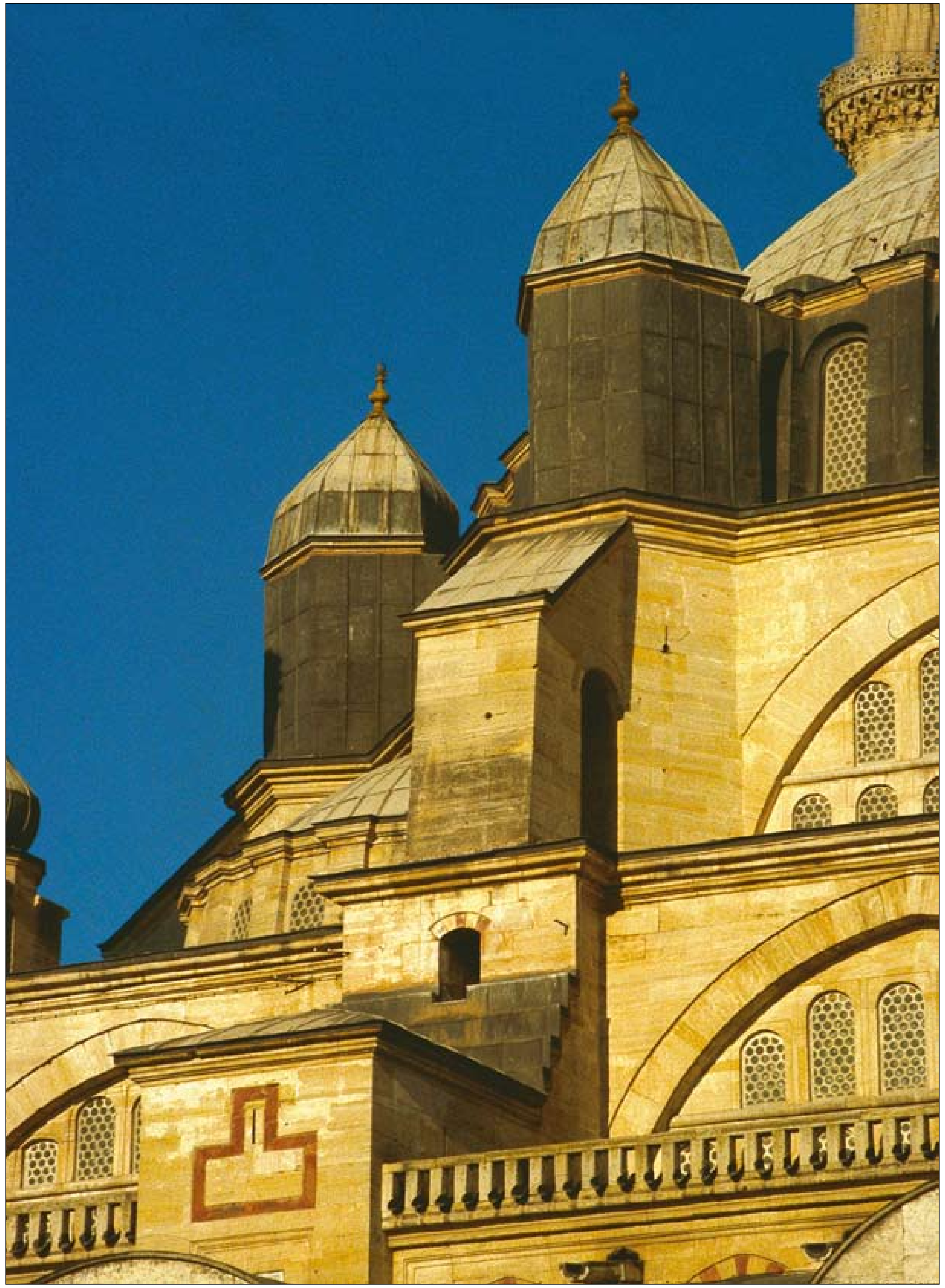
Sinan was not only an architect-structural engineer erecting buildings, but also an engineer constructing infrastructure facilities. The hydraulic engineering works of the Sinan period include of water distribution networks and aqueducts structurally supported by arches.

A short list of the most notable edifices constructed by Sinan as an architect-engineer:

- Taslimusellim Water System, twelve aqueducts and five tunnels (Edirne, 1530; extended in 1554 and/or 1575)
- Uskudar Mihrimah Sultan Mosque and the adjacent complex (Istanbul, 1547)
- Shahzadah (Prince) Mehmet Mosque and the complex (Istanbul, 1548)
- Rustem Pasha Mosque and the complex (Istanbul, 1550)
- Suleymaniye Mosque and the complex (Istanbul, 1557)
- Suleymaniye Water System (Istanbul, 1558)
- Kirkcesme (Forty Fountains) Water System including four spectacular aqueducts – Uzun, Egri, Guzelce and especially Maglova (Istanbul, 1564)
- Edirnekapi Mihrimah Sultan Camii (Istanbul, 1565)
- Buyukcekmece Bridge (Istanbul, 1568)
- Selimiye Mosque and the adjacent complex (Edirne, 1575)
- Azapkapi and Kadirga Sokullu Mosques (Istanbul, 1578-1580)

Sinan expressed that among the three most famous mosques he designed and constructed, Shahzadah Mosque in Istanbul should be considered his first great work; Suleymaniye Mosque in Istanbul was the symbol of his mastery, but he displayed all his capacity and abilities in the Selimiye Mosque in Edirne. A similar classification would also be valid for Sinan's water supply systems – Taslimusellim, Suleymaniye and Kirkcesme, displaying his great capacity and exceptional abilities in the field of hydraulic technology. These three water supply systems, the most noteworthy aqueducts since Roman times, are outstanding cultural monuments of not only the Turkish-Islamic world but also the whole of civilisation.

Selimiye Mosque



Turkey

RELIGIOUS BUILDINGS

- **Selimiye Mosque**
- Istanbul
- 1568 - 1575
- Height of minarets 71 m

Selimiye Mosque, which is considered the supreme masterpiece of the great architect Sinan was built in Edirne during the period 1568-1575, bearing the name of the then ruling Sultan Selim II. Sinan was 85 when he finished it.

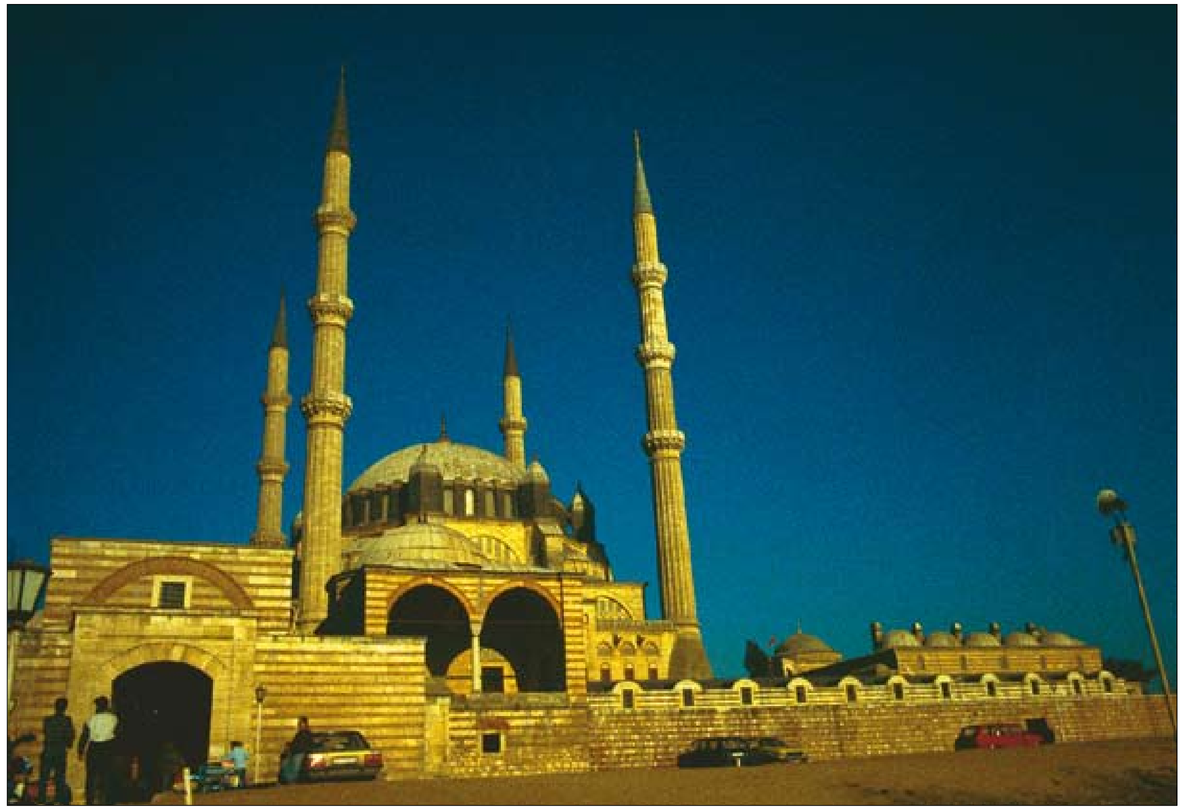
This grand mosque stands at the centre of a *kulliya* (complex), which comprises a *madrasa*, a *dar-ul hadis*, a timekeeper's room and an *arasta* (row of shops). The single central dome of the mosque, with the largest domical volume in the form of a shell of revolution, employs an octagonal supporting system created by eight columns incised in a square envelope of walls. The dome, with its 31.28 m diameter, covers about thirty percent of the mosque's 2,000 m^2 floor surface. The height of the dome from the floor is 43.28 m. The four semi-domes at the corners of the square behind the arches that spring from the columns are intermediary sections between the huge encompassing dome and the walls. The mosque's 4 minarets, each with three galleries, are 71 m high. Three separate staircases lead up to the galleries.

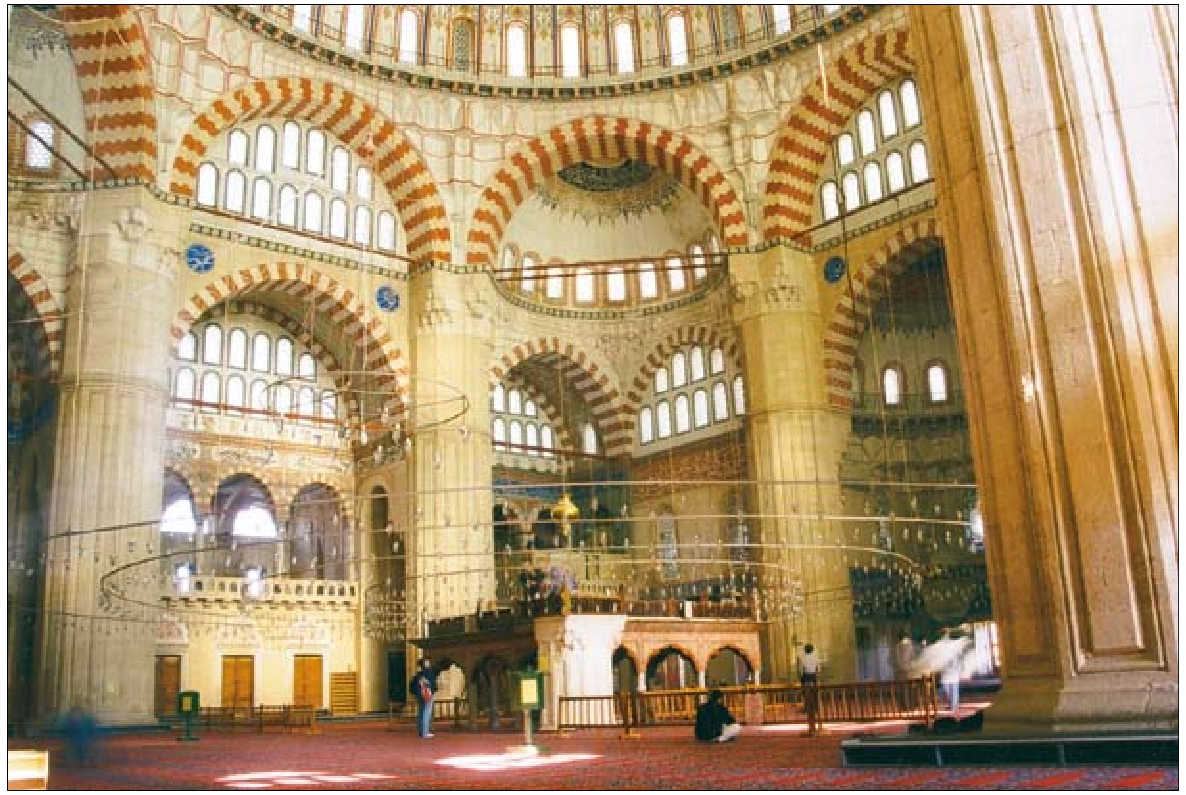
The views of elegantly and masterly arranged curved forms and surfaces are sources of profound visual pleasure. In addition, the harmonious alliance between the dome and all remaining curved components is also unique. The architect's genius is obvious in the art of combining structural functions with aesthetic considerations. Symmetry and natural light play an important role. Geometric shapes are part of every little corner of the mosque, and also of its surroundings. The use of both symmetry and natural light to create visual effects has given the Selimiye Mosque a beauty representative of the best Ottoman architecture.

Sinan's designs were full of innovation and foresight. The following are a few examples indicating the architect Sinan's extraordinary potential.

- A note was discovered during recent renovation work on the Selimiye Mosque in which he specified the method of removal and replacement of the keystone of an arch which would unavoidably be damaged over time.
- The foundation system of the Selimiye Mosque was arranged in accordance with the isolation principles of today's seismic design.
- It is a well-known fact that, before the construction of Suleymaniye Mosque, Sinan had brought all the construction materials and heaped them onto the construction area and waited for a number of years. The Sultan accused him of wasting his time and delaying completion of the construction of the mosque during his reign. However, it was later discovered that Sinan had intentionally done this to allow the soil to consolidate over the years. It must be realised that soil mechanics and the concept of soil consolidation were only invented centuries later.
- It is again known that Sinan used to test sound propagation during construction by making a standard sound and listening to it at different locations, and make the necessary adjustments. Both the acoustics and ventilation are perfect in all his mosques.

Selimiye Mosque





Turkey

Dolmabahçe Palace

BUILDINGS

- **Dolmabahçe Palace**
- Istanbul
- 1856
- Museum

Dolmabahçe Palace was the first European-style palace on the European shore of the Bosphorus between the ports of Kabatas and Besiktas in Istanbul.

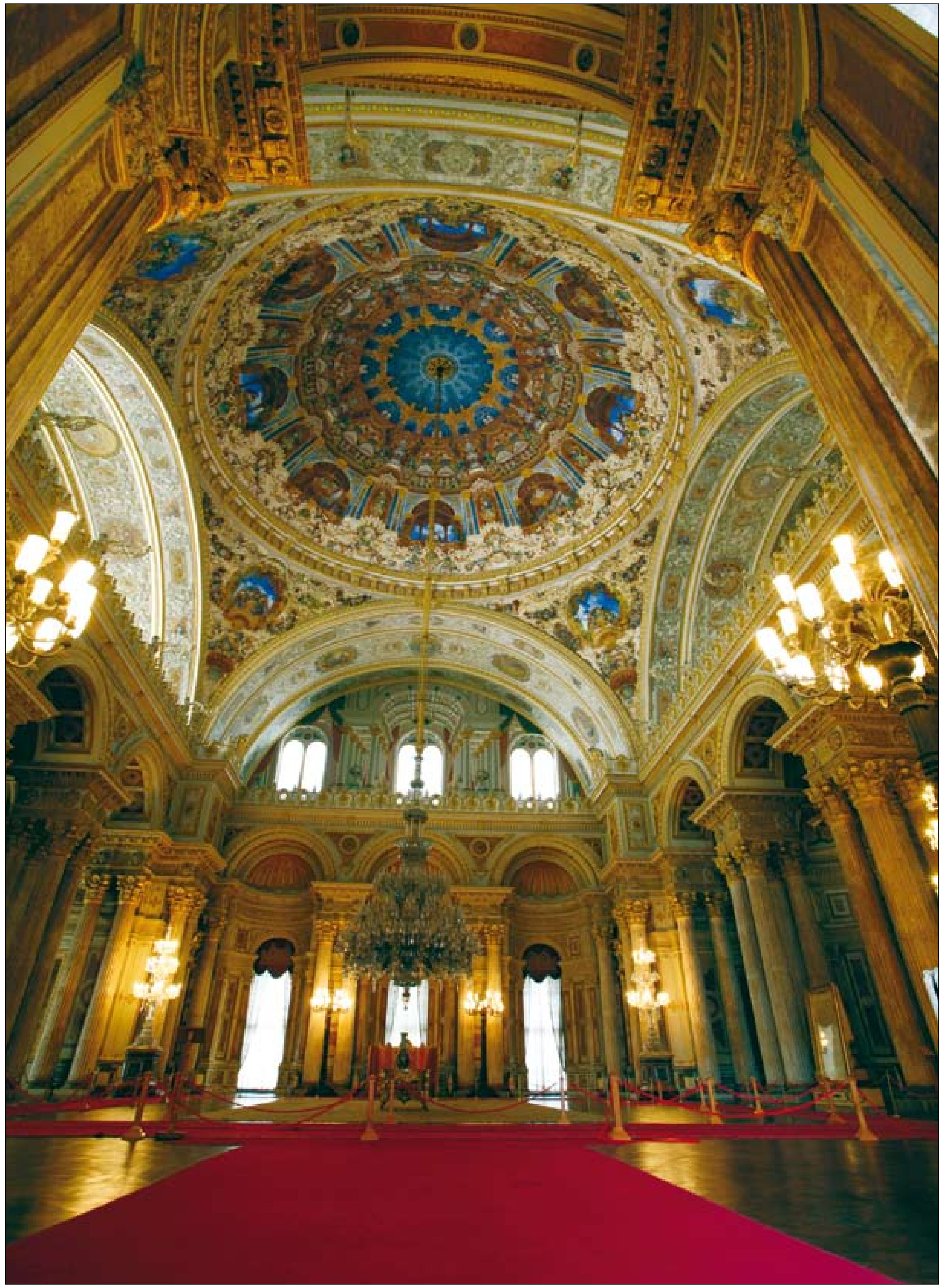
Originally the site of the Dolmabahçe complex was one of the bays in the Bosphorus until the 17th century. This bay was a natural harbour where the Ottoman admirals anchored the naval fleet and where traditional maritime ceremonies took place. It was filled with soil gradually through the years from the 17th century onwards, and became an imperial garden called Dolmabahçe (garden on fill). This garden was developed with villas, kiosks and other facilities to form an imperial complex called Besiktas Coastal Palace, built during the reigns of various sultans.

In 1843, Sultan Abdulmedjid ordered the demolition of the Besiktas Coastal Palace, which had become obsolete, and construction of a new Dolmabahçe Palace on the same site. The imperial architect Karabet Amira Balyan and his son Nikogos Balyan constructed the new palace, which was completed in 1856, including perimeter walls with two monumental gates. In addition to the main building, the palatial complex is composed of 16 separate facilities with different functions, such as stalls, mills, pharmacies, kitchens, a glass shop, foundry and patisserie. There is also a 600 m quay on the sea side.

The main building of Dolmabahçe Palace is a three-storey structure, symmetrical in plan, with 45,000 m^2 of usable floor area comprising 285 rooms, 46 halls, 6 *hamams* (Turkish baths) and 68 toilets, located on a more than 110,000 m^2 site. Although its architectural form and details are apparently influenced by some European styles, the building is the Ottoman architects' masterly interpretation of these impressions. On the other hand, the plan arrangement is an adaptation of the traditional Turkish house on a grander scale, constructed with stone exterior walls, brick interior walls and timber floors. In line with the technology of the period, the palace received its central heating and electrical systems during the years 1910-1912.

The sultans and their entourages moved to Dolmabahçe Palace, after it was completed, from Topkapi Palace, which had hosted them for nearly four centuries. Dolmabahçe then served as the official residence until the founding of the Turkish Republic.

The palace now serves as a museum and a guesthouse for foreign statesmen.



Turkey

BUILDINGS

- **Haydarpaşa Train Station**
- Istanbul
- 1906 - 1908
- Still in service

The Haydarpaşa Train Station, the most important terminus point of the Anatolian railways, is located close to Kadikoy on the Anatolian coast of the Bosphorus. It is a significant building in Turkey, not only for its location but also for its architectural and historical characteristics. The station has a very distinctive style, definitely standing out in Istanbul.

The building, with traces of Eastern European, Baroque, German Renaissance and neo-Classical influences, was designed by two German architects, Otto Ritter and Helmut Cuno. Construction started on 30 May 1906 during the reign of Sultan Abdulhamit II and was completed in a relatively short period of time and put into service on 19 August 1908. German and Italian labourers worked on the construction. The building was damaged by fire in 1917 during World War I but was subsequently restored.

The site on which the building stands was covered by the sea until 1903. The original building had been located about 1 km inland, which became insufficient due to the increasing railway transportation between Haydarpaşa and Izmit. It was decided to build a new train station, and a German company called the Anatolia-Baghdad Corporation was commissioned with the construction of the new Haydarpaşa Station. This new structure was built on reclaimed land and is therefore surrounded by water on three sides, a unique feature for a railway station. Its foundation is supported by 1100 wooden piles, each 21 m long, driven into the soft and mushy shore by steam hammer. It was initially located on a 2,525 m^2 plot of land that was later extended to 3,836 m^2.

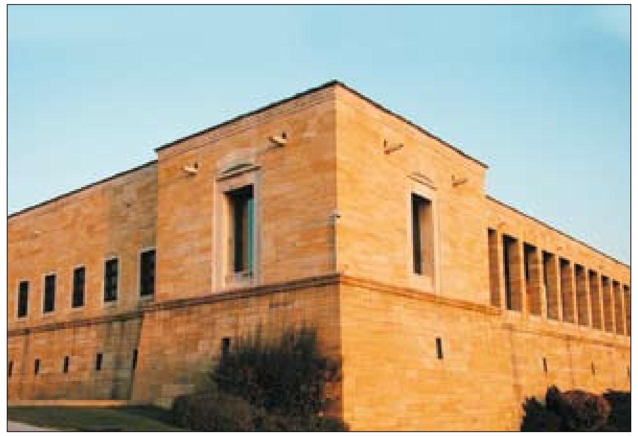
The west wing of the building is shorter, while the east wing has a long 'U' shape. There are wide corridors in the middle of the 'U'-shaped wing, and large and high-ceilinged rooms are located on both sides of these corridors. The roof, having a considerably steep slope, is made of wood and covered by slate. A big Baroque-style clock stands on the roof level of the southern façade. The clock face was first festooned with a wheeled eagle wing, which became a stylised symbol of the Turkish Railways later on.

This historical building has been very well preserved, even restored following the damage caused by a burning tanker ship in 1979, and it is still in service and hosts approximately 100,000 people every day with international, domestic and regional trains running to east- and south-bound destinations.

Turkey

BUILDINGS

- **Anitkabir (Mausoleum)**
- Anittepe/Ankara
- 9 Oct. 1944 - 1 Sept. 1953
- An important work of art



Owner: Ministry of National Defence
Architectural Design: Emin Onat, Orhan Arda
Structural Design: Feridun Arısan
Consultant: Hamdi Peynircioglu, Sabiha Gurayman, Said Kuran, Ismet Aka

This mausoleum indicates the esteem and love felt for Mustafa Kemal Ataturk. It is the most meaningful work of art of the Republic era. The location of the mausoleum, overlooking the city, enhances its structural magnificence. Its architecture, sculptures and reliefs reflect the War of Independence, the establishment of the Republic and the personal characteristics of Ataturk. The mausoleum is situated on a 15,000 m^2 site.

An international competition was organised in 1943 to select the design for Ataturk's mausoleum. The winners of the competition were Prof. Dr. Emin Onat and Orhan Arda, and construction started in 1944. The building represents Turkish history, in particular the War of Independence, and the great military, revolutionary and leadership qualities of Mustafa Kemal Ataturk. After completion of the building, Ataturk's body was transferred to the mausoleum from a temporary tomb in the Ethnographic Museum on 10 November 1953.

The mausoleum covers a large area known as Mausoleum Hill. Gardens and parks surround the building. The alley leading to the mausoleum through the gardens is called the Road with Lions, bordered on either side by 24 lion statues. To the right of the entrance is the Tower of Independence, and to the left the Tower of Freedom. In front of the towers are two groups of statues depicting three men and three women, who represent the Turkish nation.

Turkey

BRIDGES

- **Bosphorus Bridge**
- Istanbul
- February 1970 - October 1973
- A mid-span of 1,074 m
- Connecting Europe and Asia

The idea of constructing a bridge over the Bosphorus goes quite far back in history, but the actual connection of the continents of Europe and Asia had to wait until the end of the 1960s. Istanbul was experiencing rapid economic, cultural and social growth at that time, causing an upsurge in population and hence increasing traffic density.

The Bosphorus Bridge, which connected the two continents for the first time, is located over the narrow seaway connecting the Marmara Sea to the Black Sea at Istanbul. The pier supporting the bridge on the Anatolian coast is located in the Beylerbeyi district of Istanbul and the support on the European coast is at Ortakoy.

The total length of the bridge is 1,560 m, with a mid-span of 1,074 m. The width is 33.40 m, and height above sea level is 64 m. The Bosphorus Bridge became the longest suspension bridge in Europe and fourth longest in the world when it was completed in 1973. The bridge was designed to bear 6 lanes of traffic. The bridge deck has a closed box section and is suspended from the main cable by 300 ton capacity high-strength steel suspenders arranged in a triangular pattern. The bridge was designed to resist 1.0 g horizontal and 0.05 g vertical earthquake accelerations.

Owner: General Directorate of Highways
Structural Design: Freeman-Fox and Partners
Contractor: Anglo-German Bosphorous Bridge Consortium, Cleveland Bridge and Engineering Co. Ltd. (CHE) Darlington - England (fabrication of slab panels of the main free span, erection of all steel structural components including the cable system), Hochtief AG-Essen - West Germany (All piles, foundation works, anchorage blocks and concrete reinforced slab connections)
Consultant: Freeman-Fox and Partners - London Petek - Istanbul (Main bridge, toll facilities, elevators and bridge services), Freeman-Fox and Associates - London (feasibility of traffic and toll collection)
Realisation: USD 155,000,000

Turkey

DAMS

- **Ataturk Dam and HEPP**
- Sanliurfa - Bozova on the Euphrates River, Southeastern Turkey
- Nov. 1983 - Dec. 1999
- Largest dam in Turkey
- Largest HEPP in Turkey

Owner: General Directorate of State Waterworks
Contractor: Ata Inşaat San. ve Tic. A.Ş.
Consultant: Electrowatt Muh. Hiz. Ltd., Societé Generale pour L'industrie, Dolsar Engineering Limited
Realisation: USD 3,560 billion

Ataturk Dam is the largest dam in Turkey in all aspects as of its construction date. The dam ranks fourth in the world in terms of volume and ninth in terms of water reservoir capacity. In addition to its physical size it is the key project of the Southeastern Anatolia Project (GAP) that ensured the start of regional development. It is the biggest rock fill dam in Turkey and sixth in the world.

It is the largest in a series of 22 dams and 19 hydroelectric power plants built on the Euphrates and Tigris rivers in the 1980s and '90s in order to provide irrigation water and hydroelectricity to southeastern Turkey, where the climate is rather arid. Completed in 1993, the Ataturk Dam is one of the world's largest earth-and-rock fill dams, with an embankment 184 m high and 1,820 m long. Moreover, Ataturk Dam and HEPP constitute the largest hydroelectric power plant in Turkey. Water impounded by the dam feeds the power-generating units, which have an installed capacity of 2,400 MW, with an annual energy production capacity of 8,900 GWh. This remarkable capacity provided repayment of the cost of the dam within the first five years.

After producing hydroelectric energy, the water is gravity-fed to vast irrigation networks in the Harran Plain and elsewhere in the Southeastern Anatolia (GAP) region. It is the key structure for the development of the lower Euphrates River region and is responsible for providing irrigation to more than 1.8 million ha. of farmland in the Harran Plain.

Ataturk Dam Lake is the symbol of an important geographical change that has opened new horizons for the rich cultural heritage of the region. Extending over an area of 817 km^2, the dam is called the 'sea' by local people. The dam has already started to affect the daily lives of people there.

Turkey

BRIDGES

- **TAG Highway Ataturk Viaduct**
- Tarsus - Adana - Gaziantep Highway / Nur Mountain, Southeastern Turkey
- April 1993 - June 1998
- Max. span 110 m

Owner: General Directorate of Highways
Structural Design: IN-CO (Ingenieri Consulenti) Spa (Italy)
Contractor: Tekfen-Impresit Joint Venture
Consultant: Temat-Dar-DMM Joint Venture
Realisation: USD 95,000,000

The Ataturk Viaduct on the TAG (Tarsus-Adana-Gaziantep) Highway, which comprises an important section of the TEM (Trans European Motorway), crosses the Olucak Valley in the transition zone of southern and southeastern Anatolia. It is a very difficult region regarding geological, topographical and climatic conditions. The TAG Highway connects southeastern Anatolia to domestic and foreign markets, Mersin and Iskenderun seaports, Mersin, Toros-Adana-Yumurtalik and Gaziantep Free Trade Zones. Hence the TAG Highway and Ataturk Viaduct play a very important role in the rapidly increasing growth of the Turkish economy as well as that of southern and southeastern Anatolia.

The TAG Project is one of the largest investments in the world with its 258 km of highway and 41 km of connecting roads. The TAG Highway, which handles 80,000 vehicles per day, is composed of 12 viaducts, 2 special viaducts, 4 double-tube tunnels, 65 bridges, 160 underpasses and 17 cloverleaf junctions. There are also 8 parking areas, 4 service areas and 5 maintenance and operation centres along the route.

Ataturk Viaduct, the most outstanding of the viaducts on the TAG Highway, comprises two abutments and seven piers, and is made of steel box sections with a composite slab. A special type of structural steel was used which provides protection against corrosion by preserving a protective rust layer without any need of painting. The total length of the viaduct is 801.50 m, with a maximum span length of 110 m and height of 149.50 m. A total of 79,500 m^3 of concrete, 15,000 tons of reinforcing steel, 310,000 m of anchorage micropiles and ground nails, and 16,200 tons of structural steel were used in the TAG Highway Ataturk Viaduct. With all these characteristics, the Ataturk Viaduct became the largest viaduct in Turkey and second largest in Europe at the time of construction.

Turkey

TOWERS

- **Istanbul IS Bank Towers**
- Levent / Istanbul
- 1996 - 2000
- Tallest building in Turkey

The IS Bank Towers, consisting of three high-rise buildings, is a prestige project. One of these reinforced concrete towers, exceeding 180 m in height, is still the tallest building in Turkey, whereas the other two approach 120 meters. This is obviously a daring project considering the high seismicity of Istanbul. It was also impressive for being constructed in a very short period of time and for being highly cost effective.

The towers are equipped with technological systems and materials meeting the requirements of the 21st century, and have secured their place in the construction world as a project including many innovations and first applications resulting in a group of the smartest buildings in Turkey. The total construction area of the complex is 224,537 m^2.

Owner: Turkiye Is Bank
Structural Design: Severud Associates-Balkar Insaat Muhendisligi ve Musavirlik Ltd. Sti.
Architectural Design: Dogan Tekeli - Sami Sisa Architecture Office (preliminary design), Swanke Hayden Connell International (architecture), The Hiller Group (decoration)
Contractor: Tepe Insaat Sanayi A.S. - Turner/Steiner International S.A. Joint Venture
Consultant: Technical Department, Turkiye Iş Bankasi A.S., Weidleplan Consulting GmbH, TMB Structural Engineering Co. Ltd., Ankara
Realisation: USD 201,000,000

Istanbul IS Bank Towers

Turkey

INFRASTRUCTURE

- **Baku-Tbilisi-Ceyhan Oil Pipeline and Yumurtalik Plants**
- Baku-Tbilisi-Ceyhan
- January 2000 - July 2006
- Second longest oil pipeline in the world (1730 km)

Owner: BOTAS - BTC Directorate
Structural Design: ILF Muhendislik Teknik Danismanlik Taahhut ve Ticaret Limited Sirketi
Contractor: Tekfen Inşaat ve Tesisat A.S. / Punj Lloyd Limak JV / STA Joint Venture
Consultants: SOCAR, BP, TPAO, Statoil, Unocal, Itochu, Amerada Hess, Eni, TotalFinaElf, INPEX, ConocoPhillips
Realisation: USD 3 Billion (Turkish part – USD 1.4 Billion)

This project has considerably enhanced the existing strategic importance of Turkey among its neighbour countries. Being a stable and reliable country in transporting Caspian region energy sources to world markets at the start of the 21st century, Turkey has taken a strategic role in the east-west energy corridor.

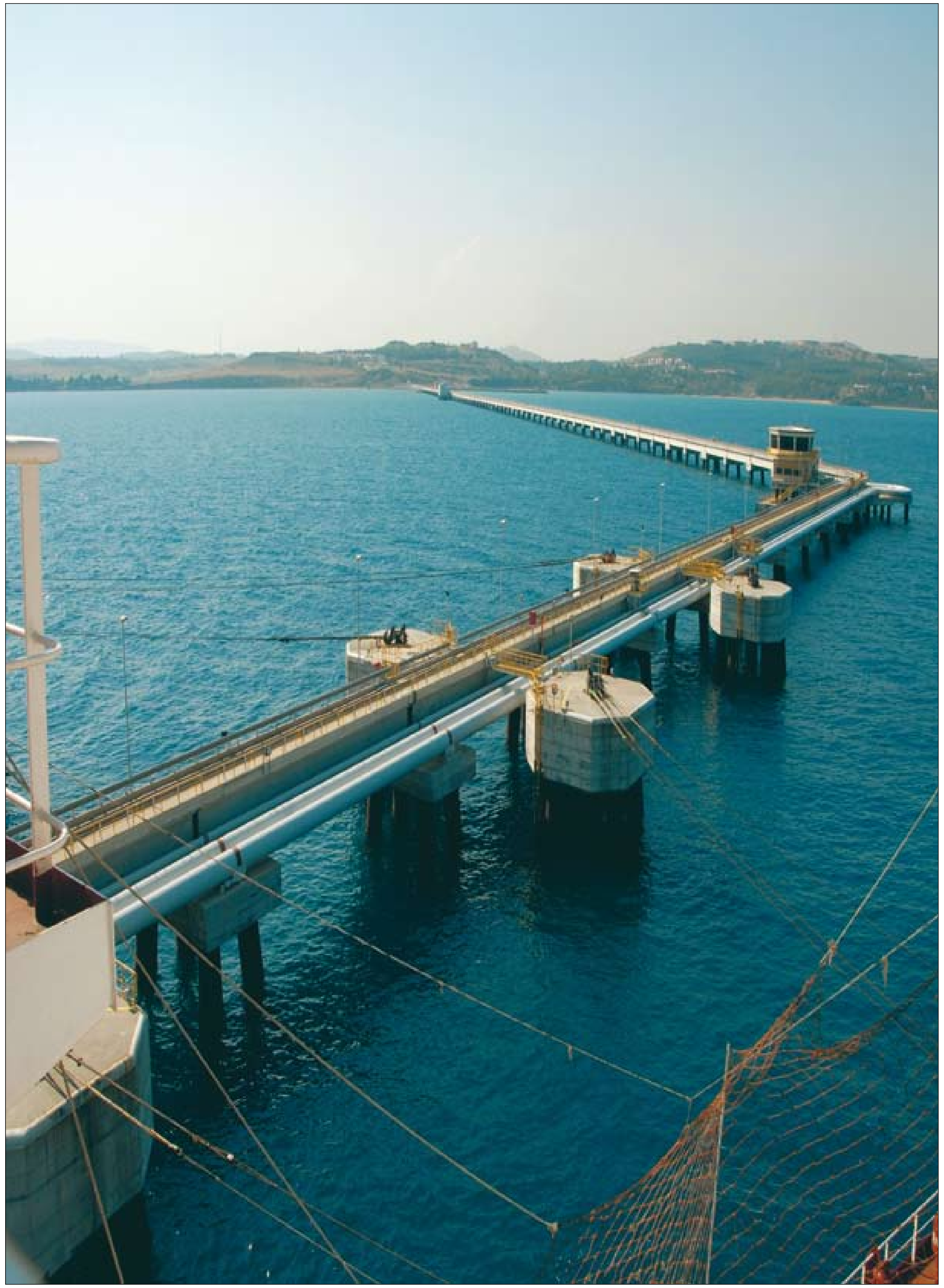
The Baku-Tbilisi-Ceyhan pipeline (sometimes abbreviated as BTC pipeline) transports crude oil 1,730 km from the Azeri-Chirag-Guneshli oil field in the Caspian Sea to the Mediterranean Sea. It passes through Baku, the capital of Azerbaijan; Tbilisi, the capital of Georgia; and Ceyhan, a port on the southeastern Mediterranean coast of Turkey. It is the second longest oil pipeline in the world (the longest being the Druzhba pipeline from Russia to Central Europe).

The construction of the BTC pipeline was one of the biggest engineering projects of the decade, and certainly one of the biggest to have occurred anywhere in western Asia since the fall of the Soviet Union. It was constructed from 150,000 individual pipe segments, each measuring 12 m (36 ft) in length. This corresponds to a total weight of approximately 594,000 metric tons. It has a projected lifespan of 40 years, and when working under normal capacity, beginning in 2009, it will transport 1 million barrels (160,000 m^3) of oil per day. The pipeline will supply approximately 1% of global demand.

Technical Features of the Project:

Maximum capacity	50 million tons/year (1 million barrels/day)
Total length / Turkish portion	1,730 km / 1,070 km
Starting point / Arrival point	Sangachal, Baku/Azerbaijan / Ceyhan Terminal, Turkey
Pipe diameter	42 and 34 inches
Design pressure	100 bar
Total pump stations	10-12
Pump stations in Turkey	4
Petroleum gravity	330 API
Number of block valve stations	51
Total excavation	15,580,540 m^3
Total backfilling	8,313,622 m^3
Total concrete	112,000 m^3
Total manpower	12,074 man-days

Baku-Tbilisi-Ceyhan Oil Pipeline and Yumurtalik Plants



Turkey

TUNNELS

- **Selatin Tunnel**
- Izmir - Aydın Highway, Belevi, Western Turkey
- 1 April 1990 - 10 April 2000
- 2 x 3-lane highway tunnel

Owner: TR General Directorate of Highways
Structural Designer: De Leuw Cather and Kutlutas Mühendislik Joint Venture
Contractor: Kutlutas - Dillingham Joint Venture
Consultant: EMG, Erer - Mayreder - Geoconsult Joint Venture
Realisation: USD 121,000,000

Selatin Tunnel involved the successful implementation of the New Austrian Tunnelling Method (NATM), where excavation stability results from the arching action in the surrounding soil without the use of any lining. Selatin Tunnel serves as the first and longest modern 2 x 3-lane highway tunnel in Turkey. It was a monumental work of engineering and one of the most significant tunnels in the world with fully computerised control systems.

The tunnel consists of a 3,043 m long tube with three lanes on the Izmir - Aydin Highway in the Aydin direction and a 3,018 m tube with 3 lanes in the Izmir direction. Total length of the two parallel tubes is 6,061 m and these two parallel tubes are connected to each other through 6 transverse passages. Some parts of these passages include administrative and control units, and two serve as emergency exits for vehicles and pedestrians.

The Selatin Tunnel was put into service in both directions on 10 April 2000. There are three 4 m-wide lanes in each tube. Maximum allowable vehicle speed in the tunnel is 80 km/h and maximum clear height is 4.80 m. The tunnels are curved in the horizontal plane, and one has a 2.6% slope.

Turkey

TUNNELS

- **Sanliurfa Irrigation Tunnels**
- Sanliurfa, Southeastern Turkey
- 1981 - 2000
- One of the longest irrigation tunnels in the world

Owner: General Directorate of Public Waterworks Administration
Contractor: Akpinar Insaat Grubu, Akpinar Yapi Sanayi A.S. - Unal Akpınar Insaat Imalat Sanayi ve A.S.
Realisation: USD 569,902,927

The Sanliurfa irrigation tunnel system, consisting of two parallel tunnels each 26.4 km long and 7.62 m in diameter, extends from the Ataturk Dam reservoir to 5 km northeast of Sanliurfa. These tunnels are among the longest irrigation tunnels in Turkey and the world.

The Sanliurfa Tunnels are important components of the Southeastern Anatolia Project (GAP), which is a multi-sector and integrated regional development project with basic objectives embracing the improvement of living standards and income levels of people in the region so as to eliminate regional development disparities and contributing to such national goals as social stability and economic growth by enhancing productivity and employment opportunities.

The water used to irrigate the Sanliurfa-Harran Plain is also used for electricity production in Sanliurfa Hydroelectric Power Plant constructed 4,100 m downstream from the tunnel outlet. The power plant, with 50 MW installed capacity, generates 124 Million kWh annually.

The Sanliurfa Irrigation Tunnels deliver water through two main canals that irrigate 476,000 hectares in the Sanliurfa-Harran Plain. An area of 327,000 hectares out of the total irrigated area is irrigated by gravity-flow and the rest, 149,000 hectares, is irrigated by pumping. The GAP started to contribute to agricultural output for Turkey at the end of 1994 when the first line of the tunnel from Ataturk Dam opened.

Turkey

TUNNELS

- **Marmaray Project**
- Istanbul
- May 2004 - expected in 2012
- Undersea connection between Europe and Asia

The Marmaray Rail Tube Tunnel and Commuter Rail Mass Transit System, or Marmaray Project, provides an upgrading of the commuter rail system in Istanbul, connecting Halkali on the European side with Gebze on the Asian side with a modern, high-capacity commuter rail system. This project is one of the largest transportation infrastructure projects in the world at present. The entire length of the upgraded and new railway system will be approximately 76 km. The main structures and systems include an immersed tube tunnel, bored tunnels, cut-and-cover tunnels, at-grade structures, three new underground stations, 37 new surface stations, operations control centres, yards, workshops, maintenance facilities, upgrading of existing tracks including a new third track on ground level, completely new electrical and mechanical systems and procurement of modern railway vehicles.

The Marmaray Project offers many special challenges, of which the most important are as follows:

- The immersed tunnel under the Bosphorus will be the deepest built so far, with its deepest point some 58 m below the water surface.
- Istanbul and its surroundings will most likely experience a seismic event of up to 7.5 magnitude during the lifetime of the project.
- The ultimate capacity of the commuter rail system will not be less than 75,000 passengers per hour per direction. This necessitates special provisions for the safety of people in the tunnels and deep stations.

- The marine work will have to be performed in very deep waters in a waterway that carries more than 50,000 ships every year, and additionally a vast number of ferries and passenger boats which cross the Strait.
- The deep stations and tunnels will have to be constructed in an area where civilisation can be traced back more than 8,000 years, so removal and preservation of historical heritage is therefore a special focus.

Construction of the Marmaray Project started in May 2004 and still continues at a rapid pace. Its completion, expected to occur in 2012, is projected to increase the fraction of trips in Istanbul made by rail transport from 3.6% to 27.7%. If this takes place, Istanbul's rail transport fraction will be the third largest in the world, after Tokyo (60%) and New York City (31%).

The Treasury of Turkey, under the Ministry of Finance, is responsible for arranging the financing of the Marmaray Project. The Japan Bank for International Cooperation (JBIC) and the European Investment Bank (EIB) have provided major financing for the project. Total cost of the project is expected to be approximately EUR 2.5 billion (USD 3.6 billion).

Turkey

BUILDINGS

- **Atatürk Olympic Stadium**
- Ikitelli / Istanbul
- January 1998 - December 2001
- One of the world's largest stadiums
- 80,000 seats

All photos granted by Freyssinet, France

Owner: National Olympic Committee of Turkey
Architects: Michel Macary and Aymeric Zublena, (Designers of the Stade de France, Paris, which hosted the 1998 World Football Championships)
Structural Design: Tekfen Engineering Corp. (R.C.), Gök Construction & Trade Corp., (prefabricated R.C.), Cabinet Jaillet-Rouby Ingenieurs Conseils, France (steel structures)
Contractor: TEKFEN Construction and Installation Co., Inc., - Campenon Bernard SGE-SAE International (France) JV
Realisation: USD 140,000,000

Atatürk Olympic Stadium seats 80,000 spectators, which makes it one of the world's largest stadiums, as mentioned in the book *Stadi del Mondo* published in 2004 by Edizioni Gribaudo of Italy. It is an assertive project built to the highest international safety and construction standards to support the city's Olympic goal, including a 9-lane-track main athletic field, 24,000 m^2 training area, 25,000 m^2 athletic warm-up field, 42,200 m^2 commercial building and facilities, an amphitheatre and two elevated car parks.

The complex was granted a '5-star sports complex' rating by UEFA in 2004 with its superior technical infrastructure ensuring perfect visibility from any point in the stands, a homogeneous sound level of 102 decibels, 1,400 lux illumination at every point, and 148 exit gates that allow for emergency evacuation of the entire stadium in only 7.4 minutes.

The stadium is a state-of-the-art facility with two steel roofs. The west roof covers an 18,600 m^2 area, which was designed in the form of a crescent of structural steel weighing 3,420 tons, principally composed of a 1,000 ton main beam called a mega-truss supported by two reinforced concrete shafts with a 196 m span. To hang the roof, 15 tons of Freyssinet cables were used and fixed with special Freyssinet HD anchorages. The total construction area of the complex is 120,000 m^2.

Atatürk Olympic Stadium

Atatürk Olympic Stadium

Content

European Council
of
Civil Engineers

ECCE member organisations

(Situation as per August 2009)

BULGARIA
СЪЮЗ НА СТРОИТЕЛНИТЕ ИНЖЕНЕРИ В БЪЛГАРИЯ (ССИБ)
Union of Civil Engineers in Bulgaria (UCEB)
www.uceb.eu

CROATIA
Hrvatska komora arhitekata i inženjera u graditeljstvu
Croatian Chamber of Architects and Engineers
www.hkaig.hr

CYPRUS
Cyprus Council of Civil Engineers
(representing 3 organizations: Cyprus Civil Engineers & Architects Association, Cyprus Association of Civil Engineers, Union of the Chambers of Cyprus Turkish Engineers and Architects / Chamber of Civil Engineers)

CZECH REPUBLIC
Český svaz stavebních inženýrů / Česká komora autorizovaných inženýrů a techniků činných ve výstavbě
Czech Institution of Structural & Civil Engineers / Czech Chamber of Certified Engineers and Technicians
www.cssi-cr.cz / www.ckait.cz

ESTONIA
Eesti Ehitusinseneride Liit
Estonian Association of Civil Engineers
www.ehitusinsener.ee

FINLAND
Suomen Rakennusinsinöörien Liitto
Finnish Association of Civil Engineers
www.ril.fi

FRANCE
Conseil National des Ingénieurs et des Scientifiques de France
National Council of Engineers and Scientists of France
www.cnisf.org

GREECE
Σύλλογος Πολιτικών Μηχανικών Ελλάδος
Association of Civil Engineers of Greece
www.spme.gr

HUNGARY
Magyar Mérnöki Kamara
Hungarian Chamber of Engineers
www.mmk.hu

IRELAND
Institution of Engineers of Ireland
www.iei.ie

ITALY
Consiglio Nazionale degli Ingegneri
National Council of Engineers
www.tuttoingegnere.it

LATVIA
Latvijas Būvinženieru savienība
Latvian Association of Civil Engineers
www.lbs.building.lv

LITHUANIA
Lithuanian Association of Civil Engineers
www.lsis.lt

MALTA
Kamra tal Periti
Chamber of Architects and Civil Engineers
www.ktpmalta.com

MONTENEGRO
Inženjerska komora Crne Gore - Komora Građevinskih Inženjera
Engineers Chamber of Montenegro - Civil Engineers Chamber
www.ingkomora.me

POLAND
Polish Society of Civil Engineers

PORTUGAL
Ordem dos Engenheiros
Order of Engineers
www.ordemengenheiros.pt

ROMANIA
UAICR
Union of Associations of Civil Engineers of Romania
manoliu@hidro.utcb.ro

RUSSIA
Russian Society of Civil Engineers

SLOVAK REPUBLIC
Slovenská komora stavebných inžinierov
Slovak Chamber of Civil Engineers
www.sksi.sk

SLOVENIA
Inženirska zbornica Slovenije
Slovenian Chamber of Engineers
www.izs.si

SPAIN
Colegio de Ingenieros de Caminos, Canales y Puertos
www.ciccp.es

TURKEY
İnşaat Mühendisleri Odası
Turkish Chamber of Civil Engineers
www.imo.org.tr

UNITED KINGDOM
Institution of Civil Engineers (ICE)
www.ice.org.uk

European Council
of
Civil Engineers

European Council of Civil Engineers

was created in 1985 out of the common concern of the professional bodies for Civil Engineers in Europe that the Civil Engineers working together across Europe could offer much more to assist modern European society with sustainable designs, practical use of research & development, and economic and well funding structures.

OBJECTIVES

European Union

- Promote the highest technical and ethical standards;
- Provide a source of impartial advice;
- Promote co-operation with other pan-European organisations in the Construction Industry;
- Contribute towards professional recognition of qualifications and mobility in the framework of existing EU directives.

National Governments and Institutions

- Advice and influence individual governments and professional Institutions;
- Formulate standards and achieve a mutual compatibility of different regulations controlling the profession;
- Formulate standards for a European Code of Conduct of the Civil Engineering Profession and disciplinary procedures applicable throughout the Union.

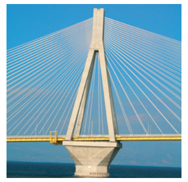
Profession, Related Organisations and Industry

- Formulate guidelines to maintain and raise standards of civil engineering education; training and professionals' competence;
- Assist in achieving mutual compatibility of Eurocodes, standards and regulations in the related industry;
- Encourage and improve levels of safety and quality in the industry






CURRENT ECCE PRIORITIES




- The Civil Engineering Profession & Civil Engineering Services in Europe
- Education, Training and Continuing Professional Development of Civil Engineers
- Supporting the Activity of Small and Medium Enterprises with regard to Civil Engineering
- Protection and Upgrade of the Urban and the Natural Environment
- Business Development and Legislative Framework for Civil Engineers in Europe
- Research and Technology & Innovation in Civil Engineering
- Active ECCE involvement in EU Policies and related Financial Tools, Initiatives and Programmes
- Meeting the special requirements and support to our National Member Organizations
- Cooperation with other European and International Engineering Organizations

CURRENT ECCE STANDING COMMITTEES

- Education & Training
- Environment & Sustainability
- Development & Business Environment
- Knowledge & Technology
- Professional Recognition & Mobility

ECCE MEMBERSHIP

Membership is open to national professional organisations of Civil Engineers in Europe. Associate membership is open to European non-governmental organizations, contracting and consulting companies, and other organizations.
The current membership is made up of member organizations from BULGARIA, CROATIA, CYPRUS, CZECH REPUBLIC, ESTONIA, FINLAND, FRANCE, GREECE, HUNGARY, IRELAND, ITALY, LATVIA, LITHUANIA, MALTA, MONTENEGRO, POLAND, PORTUGAL, ROMANIA, RUSSIA, SLOVAK REPUBLIC, SLOVENIA, SPAIN, TURKEY, UNITED KINGDOM.

MEMBERSHIP IN EUROPEAN AND INTERNATIONAL ORGANIZATIONS

ECCE is a member of World Council of Civil Engineers. (WCCE), European Council for Construction Research, Development and Innovation (ECCREDI), European Society for Engineering Education (SEFI), European Construction Forum (ECF) and also a member of the European Civil Engineering Education and Training (EUCEET) Association.
ECCE also maintains continuous and close cooperation with European Council of Engineers Chambers (ECEC), European Federation of Engineering Consultancy Associations (EFCA), World Federation of Engineering Organisations (WFEO) and European Federation of National Engineering Associations (FEANI).
ECCE has formal agreements with counterparts across the globe - American Society of Civil Engineers (ASCE) and Japan Society of Civil Engineers (JSCE).

www.ecceengineers.eu

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