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Metal bridges: three thousand years of evolution

The Arkadiko Bridge in Greece is one of the oldest bridges in the world that has been handed down to us and is still used. Built in the Bronze Age, it is approximately 3,300 years old.

Did builders think during the Arkadiko Bridge's construction, using limestone boulders in a fashionable Mycenaean brickwork manner called Cyclops, without using cement, that not only locals, but also crowds of tourists would walk on it thousands of years later? How far ahead do modern bridge builders look when they build their bridges? What is the composition of

metal bridges

and what building materials are used for bridges?

Beam bridges

Before delving deeper into this topic, we should mention that any bridge is mostly composed of spans (among other functions, they are used for motor roads and railway, as well as in general for pedestrian crossings or pipelines) and supports.

Bridge design is defined by spans – from the simplest beam, arch, truss, suspended and frame bridges to more complex cable-stayed ones (there are also other less common types of steel bridges). Spans rest on supports and the latter rest on the bridge foundation.

In addition, if you plan to build a steel bridge, you will need basic structural elements: beams, arches, trusses and suspensions. Different combinations of these four components allow architects and bridge builders to implement the most fantastic design solutions.

So, once again, beam bridges are the simplest type of such structures. The role of spans for such bridges is played by beams covering distances between supports.

From the viewpoint of the laws of physics, the beam system is characterised by the absence of horizontal load applied by spans on supports because the load is applied only vertically.

A commonly known type of basic beam bridge is a wood plank thrown over a pool, or a

log or stone slab

connecting the two banks of a brook. Beams for larger bridges are made of concrete or steel. As a rule, concrete is used for short bridges in rural localities. In general, the term “beam” usually means precisely a steel bridge beam, which most often means metal bridges using beam systems.

Beam bridges are the oldest type in the world; their history started thousands of years ago. However, they are still used. Their design was, for sure, much simpler several centuries ago. As technologies have evolved, materials and methods have improved, from stone processing and the invention of concrete to forged iron and, finally, steel, which is stronger and has a longer service life.

The length of a beam bridge rarely exceeds 76 m (this is a matter of physics and restrictions dictated by the structure itself). Nevertheless, there are exclusions.

The main span of the famous Rio-Niterói Bridge, which is the longest road beam bridge in the world, is a record 300 m. This construction is also called the President Costa e Silva Bridge. It crosses the Guanabara Bay and connects two Brazilian cities – Rio de Janeiro and Niterói. Companies from various countries around the world took part in the bridge’s construction. For example, steel elements of the spans (including steel bridge beams) were manufactured in the UK, from where they were transported by sea to a Brazilian island not far from the site for further assembly in several stages. The bridge took six years to build and was opened in Rio-Niterói in 1974. It was named after the late president of the country who initiated the project but did not live to see its implementation.

Another example of a beam bridge is the pedestrian and motorcycle bridge crossing Volodomyrskiy Uzviz (also known as Vladimirsky Spusk or Vladimirsky Descent), a street in Kyiv. The bridge connects the monument to Volodomyr the Great and the Peoples' Friendship Arch. While the idea of construction existed for decades, the implementation of the ambitious project started only at the end of 2018. It was opened to the public in May 2019, by the Day of Kyiv. About 90% of materials of this mainly metal bridge were manufactured in Ukraine. In particular, 700 tonnes of steel sheets with various thicknesses (8-55 mm) were manufactured by Azovstal, the Ukrainian industrial giant.

Box beam bridges

Box beam bridges represent boxes made of concrete, steel and reinforced concrete beams (in different combinations). As a rule, this type of bridge is used to build modern above-ground structures for municipal rail transport vehicles.

Box beam bridge creation is closely connected with the name of the French Lieutenant General Giffard Le Quesne ("Q") Martel, who served during the First World War and Second World War and was a pioneer of military engineering and tank combat strategy. In 1919, the officer was appointed as the head of an experimental bridge complex in Christchurch, Hants, who studied the possibilities for using tanks for engineering purposes. Martel thought of connecting the bridge to a tank to use its motor energy for manoeuvring while positioning the facility on site. The officer also developed the concept of a modular box beam bridge, which was new at that time. Such a modular bridge was relatively easy to build while troops advanced during military campaigns. The concept was officially accepted by the French Army in the 1930s.

As for non-modular box beam bridges, they were more popular during the rapid growth of road construction in the 1960s, when a lot of bridges were built simultaneously. The unprecedented haste caused errors. The popularity of this type of design was affected considerably by three major accidents in Australia, Germany and the UK when such bridges collapsed. In England, the Merrison Committee was established to study the design and methods of building steel box beam bridges. The problem turned out to be related to design solutions and errors in bridge

construction. Later on, some beam box bridges were rebuilt (to a greater or lesser degree) and additionally reinforced.

Truss bridges

Spans are made of either solid beams with different cross sections or truss structures, which are also called beams. Trusses are, as a rule, metal railway bridges. Trusses are made of rolled steel. Their lightness makes it possible to cover relatively large spans of 40-150 m.

A reinforced concrete bridge truss is used for access railway tracks at enterprises in Russia's Kemerovo region..

The US has quite an illustrative history of truss bridge development. There was no shortage of wood and, therefore, well-tailored timber and iron bars were usually used for early American bridge trusses. In 1820, the simplest shape was patented – the Town lattice truss. Its manufacture required neither specific skills nor a large amount of metal. Until the mid-19th century, completely steel bridges were rare in America. Metal started gradually replacing wood and bridges began to be made using forged metal. Construction companies developed a lot of projects with trusses of various shapes and they were sold successfully throughout the country. The popular bowstring truss was followed by the Pratt truss. By the end of the century, forged iron bridges were replaced by steel bridges. Other truss structures, including the Parker camelback truss, were also used at that time. By the 1910s, most developed countries developed and standardised a lot of truss designs. Today, there are several dozen truss systems used in bridge construction.

The Pont de Québec truss bridge, also known as the Quebec Bridge, features the longest cantilever bridge span in the world. It connects Quebec and Lévis in Canada; its span is almost 550 m long. It collapsed during construction (and this event, by the way, is not rare). Calculation errors at the stage of the bridge planning led to a considerable excess of the actual bridge weight over its bearing capacity. Upon the bridge's completion, the local engineers noticed some structural problems, but nobody took their severity into account. The work continued independent of the principal engineer's demand to completely stop construction. As a result, the unfinished structure collapsed in 15 just seconds in 1907.

In the 2000s, damaged parts of the Pont de Québec are still being washed ashore by outflows. The local historical community used this metal to build a monument to the catastrophe. Nevertheless, the Pont de Québec was commissioned in 1919. Today, it has been conferred the honorary title of historical monument to civil engineering. There is a myth in Quebec that pieces of the fallen bridge span have been used for many years to forge the steel rings that are presented to future Canadian engineers at an official ceremony upon graduation. These rings are worn on the little finger and are intended to remind the student about both social duties and professional ethics. The steel ring is initially rough but becomes smooth over the time, symbolising the experience gained with age.

Arch bridges

Arch bridges belong to so called anchor systems. They differ from beam bridges by the fact that their spans transfer both vertical and horizontal load to supports. Arches represent the main bearing structure of such a structure.

Arch bridges are a masonry classic; the first one is 33 centuries old Arch structures were used for bridge construction not only by the ancient Greeks, but also by the Etrurians. The ancient Romans appeared to be the ones who understood all the opportunities of such systems.

Modern historians and architects have counted more than three hundred Roman stone bridges, three dozen wooden structures and fifty aqueducts, most of which have not only survived to our day but are still used by pedestrians and car drivers!

The Roman arch bridges were mostly simple hemispherical structures. Some of them were made as a series of arch segments. Roman bridge builders were also the pioneers in building concrete bridges. The Roman practices largely formed the basis of successes of European architects in the Middle Ages. Supports became narrower, arch barrels became thinner and spans became higher. By the 14th century, the length of arch bridges reached 40 m in Spain, Italy and France.

The Anji Bridge, in turn, is the pride of Greater China, as it is the oldest bridge preserved in the country. This object was built in the 5th century and still exists almost without changes (despite eight wars, ten major floods and numerous intense earthquakes). The bridge's length is 50 m, its span is 37 m and its width is 9 m. At the time of its construction, the Anji Bridge was considered an engineering triumph. The ancient engineer Li Chun used side arches in the bridge structure, which made it more stable. Interestingly, European bridge builders did not have the same idea until the 14th century.

Stone and brick bridges still inspire new generations of engineers and builders. The father of the modern design principles for stone arch systems is France's Jean-Rodolphe Perronet. His best-known work is the Pont de la Concorde over the Seine River. This structure, which was built during the French Revolution, continues to bear heavy Paris traffic.

Finally, Ukrainian metal arch bridges deserve no less of our attention. The longest one is a metal bridge over the Dnipro River connecting the right bank in the city of Zaporizhia and Khortitsa Island. Roughly speaking, it is composed of a metal arch, a steel cable-stayed girder resting on the arch, and a reinforced concrete slab. Such a structure allowed the bridge's builders to achieve a length of 320 m, making it the longest arch bridge in Ukraine.

In 1970, the DniproHES-2 hydroelectric plant began to be built and, at a specific stage, it became necessary to shut down vehicle passage over the existing DniproHES-1 dam. As there were not enough available bridges remaining to meet the city's logistical needs, they decided to build the new bridge over the Dnipro River. Steel structures for the bridge were manufactured at Babushkin Plant in Dnipro; the construction was also installed by bridge builders from Dnipro. The installation was followed by testing bearing structures. To do this, fifty trucks weighing 25 tonnes each were used. The bridge required reinforcement and the result exceeded all expectations.

At that time, this was the only bridge of its kind in the USSR and, possibly, in the world. According to architects, the combination of such a large span with a flexible and rigid steel arch was unique. It was opened to traffic in 1974 and reconstructed in the 2000s. It is still in use today.

Steel advantages in bridge construction

Studying the evolution of individual bridge crossings, one can see how masonry structures were replaced with concrete and steel bridges and then completely with steel structures.