History of Bridges - A philatelic review

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ABSTRACT: This paper is an informal introduction to the theme of bridges, combining the "disciplines" of bridge engineering, history, and philately. It is an updated brief summary of an earlier publication [1]. A brief history of the bridge development, and the design process is summarized and examples of the different types of bridges are presented. As illustrations selected stamps from own stamp collection are used.

1 INRODUCTION

Bridges have fascinated mankind over time. They have been symbols of art and science, good architecture, trade, and engineering skill. They have also symbolized links between people, communities, and nations. Strategic and tactical bridges have been of importance for exercising power. Bridge building has therefore been a high-ranked profession.

2 HISTORY

2.1 Early bridges

Bridge building is a very old art of man. The first bridges were stone and wooden bridges, including natural bridges, single stone plates, rope bridges and wooden beams crossing a brook. (Figure 1a,b,d)

Primitive stone bridges developed from slate stones to simple arches built of stones laid on top of each other with slight offset, until they met in the middle. This kind of arches can be found in the ancient Egypt, Greece, Asia minor and Mexico. Such a construction method only allowed short spans. It was the invention and use of the genuine arch, by the Etruscans about 700 BC, that made it possible to build larger spans.

Floating bridges were also used a long time ago. Xerxes' bridge across Hellespont in 480 AD in the war between Persia and Greece is well known. [4].

Bridges were also built in the Far East a long time ago. Accounts of bridge construction in China and Tibet give evidence of this [2], but few detailed facts exist.

Some examples of early bridges that exists today, are Tarr Steps in Exmoor, England (1b), built about 1000 BC, and an arch bridge across the river Meles by Izmir in Turkey, built about 850 BC.

Figure 1 Natural and early manmade bridges. a Puente del Inca. Medoza. Argentinean natural bridge. b Tarr Steps England 1000 BC. c Chinese stone arch bridge d Gabon rope bridge.

2.2 Bridges as symbols

Bridges have symbolized links between people, communities, and nations. The rainbow can be found as a symbol of bridging gaps or marking connections between continents (2a). Links between the Nordic countries and Bulgaria are symbolized by the suspension bridge with a flag girder (2b). You also find bridges as symbols in the mythology and in religions. In Jakobs dream in the Bible, we find the stairway (bridge) from earth to heaven. (1c).

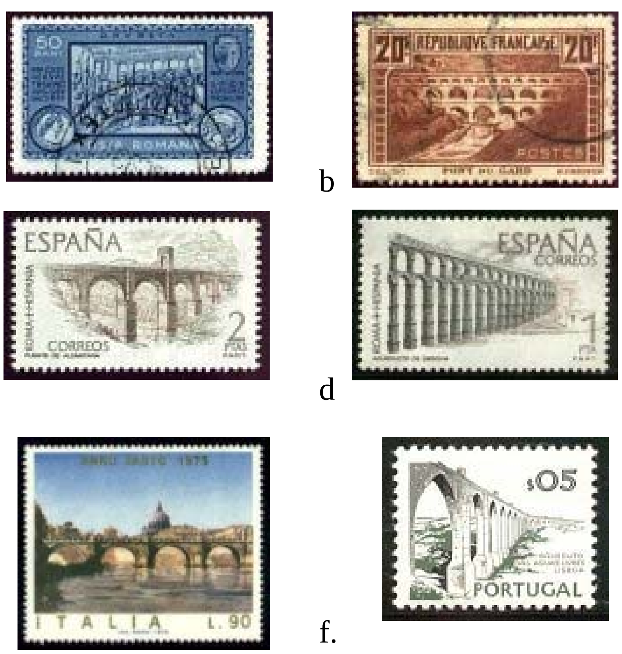
a b c

Figure 2. Bridges as symbols. a. Rainbow. b. Suspension bridge with flag girder c. Jakobs dream. Stairway (bridge) from earth to heaven.

2.3 Roman bridges

The Roman period was a peak in the history of bridge construction. A necessary condition for the efficient governing of the Roman Empire was good communications. As a consequence of this, the art of bridge construction showed an impressive development. The roman attained an extremely high technical level and still today, we can admire, and even use, the viaducts and aqueducts built 2000 years ago (Figure 3). Today only the stone bridges have survived the wear and tear of history, but the Romans also built outstanding wooden bridges (3a)

Romans were aware of the static function of the arch and bridges with a span up to 40 meters were built. The Roman arch was semi-circular and consequetly had a limiteder potential for the span width. A development towards flatter bridges and larger spans came letter. Pont du Gard at Nimes (France) (3b), Ponte Sant' Angelo, Rome, (Italy) (3e) and Ponte di Trajano across the river Tejo in Spain (3c) are among the most well-known Roman constructions . Alo the aqueduct in Segovia (Spain) built about 100 AD is one of the finest Roman buildings still standing (3d).



a b c d e. f.

Figure 3 Roman bridges a. Roman wooden bridge (99BC from Trajan column) b. Pont du Gard ,Nimes, France (18 BC), c. Ponte di Trajano, Spain (98-117 AD). d. Aqueduct Segovia, Spain (100 AD) e.Ponte Saint Angele, Rome, Italy (134 AD) f. Aqueduct Das Aquas Livres, Lisboa, Portugal.

2.4 Early Chinese and Japanese bridges

China has a long tradition in bridge building. Early Chinese bridges included stone and wooden bridges and rope bridges as well. Examples are given in Figure 3 and demonstrate the engineering skill. The An-Chi bridge across the river Chiao China, built in 610 AD and still existing, gain distinction by the shallow arch. (4a). The An-Lan rope suspension bridge in Kuanhsien China (4b) , built about 900 AD which has eight spans and a total length of about 325 meters, is a remarkable bridge. The Kintaibashi wooden arch bridge across Nishikigama in Japan (4c) built 1677 is typical for early Chinese and Japanese wooden bridges.

a b c

Figure 4 Chinese and Japanese bridges a. The An-Chi bridge China (610), b. The An-Lan bridge China (610). c. Kintaibashi Bridge (Japan 1677).

2.5 Medieval and renaissance bridges

With the fall of the Roman Empire, the development within the art of bridge construction halted. Most of the medieval bridges were built by the priests, or under their patronage and direction. Then the priests were followed by the kings in bridge development and organization because toll bridges became power and business. We have excellent examples of their work still standing and in service.

Later development, however, made one abandon the Roman stone bridges' half-circles in favor of elliptical arches and slimmer constructions with longer spans. Pont d'Avignon, built 1177-1188 with 21 spans and a total length of over 900 meters was for a long time the longest bridge in Europe (5b)

With the emergence of the renaissance and modern times, the building of bridges flourished again. The establishment of trade routes and not least the growth of large cities, made bridges necessary. Le Pont-Neuf (5d) built in 1578-1604 which is one of the most famous bridges in Paris, may stand as an example of this period.

a. 

b. 

c. 

d 

e. 

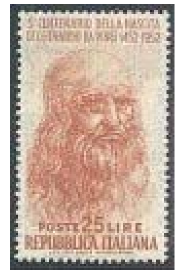
f 

Figure 5 Medieval and renaissance bridges. a. St Martins bridge Tolejo (Spain). b. Pont d'Avignon (France 1188). c. Pont Valemtré (France 1308-1380). d. Pont-Neuf , Paris, (France 1578-1604) e. Floating bridge Budapest (Hungary) f. Stari Most Yugoslavia (1566, destroyed by war actions 1993)

2.6 Science and applied mechanics

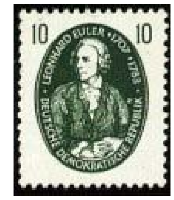
All along, up to the eighteenth century, the building of brides was a typical skilled trade, based on experience of generations. The people involved had developed an admirable understanding of the forces of nature. On the basis of this they had developed empirical rules of construction to lean on.

The origin of the science of mechanics was most likely at the time of Navier, just after the turn of the century 1700-1800. Before him there had, however, been a number of outstanding representatives of the science of mechanics, where names like Archimedes, Leonardo da Vinci, Gallilei, Hooke, Bernoulli and Euler can be mentioned. (figure 6).



a

b



c

Figure 6 Representatives of the science of mechanics.
a. Leonardo da Vinci. (1452-1519) b. C.A.Coulomb, (1736-1806) c. L. Euler (1707-1783)

All their work is .related to the natural sciences and did not have any direct influence on the construction of structures, as their works were not available to the people in the handcrafts.

Building assignments became, however, bigger, both in terms of number and proportions. Economic conditions came into play, and also new building materials made it necessary to add the ancient art of construction with a scientific- or more theoretical instrument, namely statics. A couple of names will therefore be mentioned in the context of their contributions to the subject and hand

The building of stone bridges was for a long time based on empirical rules. Theoretical considerations were added to the construction work, starting with Lahire in 1695, when the compression line of arch was defined. The practical application of this theory came with a construction performed in 1729. Coulomb developed the theory of arch using models to study the development of a bridge breakdown. His works were published in the mid-1700s. Culman introduced calculations of bridges with an elastic center of gravity about 1850. The analysis of bridges had thereby taken a major step forward.

In Europe wooden bridges from the 13th century still exists. At that time the construction was mostly based on tradition and empirical knowledge. Big wooden bridges and steel bridges, however, had a strong development among with the static of trusses. Grubenmann who in 1757 made the big bridge in Shaffhausen (Switzerland) with a span of almost 100 meters, probably did not know this scientific development. The truss theory was acknowledged in Russia in the 1840s, however, while Culman was the first one to systematically apply graphic methods for the analysis of trusses (1866). Maxwell, Cremona and Mohr, just to mention a few performed a further development of the truss theory. In the USA special wooden truss systems were developed and later used in road and rail bridges.

About the middle of the 18th century bridge construction began to assume a more scientific aspect than before. Production of iron and steel in. commercial scale gave new possibilities. Bridge building activity increased rapidly with the introduction of the railway all over the world

a. 

b. 

Figure 7 Wooden and masonry bridges. a.. Neubrügg bridge. (Switzerland 1535) b. Göltzschtalviaduct Mylay (Germany 1850)

2.7 The steel revolution

Although the first record of western use of iron in bridges was about 1740, the rise of iron to a dominant position as a structural material was in the period of 1830 to 1880. Iron trusses replaced the wooden bridges. Cast iron was first used in arch brides (8a). A combination of cast iron for compression members and welded iron for tension members was first used in truss structures, but from 1840 onwards, especially for railroad bridges, welded iron was used solely.

The development of the theory of structures in the 19th century was in the area of truss analysis. The truss bridge design reached a milestone in 1889 with the Firth of Forth Bridge with a main span of 521 m and still in service. The Quebec bridge from 1918, similar the Forth.-bridge has a main span of 548,5 meters (8c).

Examples of large steel truss arches may be the Sidney Harbor Bridge, (8d) in Australia and the Kill van Kull Bridge in the USA built in the 1930's with span widths above 500 m. .

In modern steel bridge design the plate girder and steel box girders are used for medium and large span widths (8e). High steel qualities, welding technique and painting systems make steel bridges competitive

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a. 

b 

c. 

d. 

e. 

Figure 8 Steel bridges a. Ironbridge Shropshire, (GB) b. Müngstener bridge (Germany 1897) c Quebec bridge (Canada 1918) d. Sidney Harbor bridge (Australia 1930) e. Steel plate girder bridge .

2.8 Suspension bridges

The suspension bridges are able to bridge long spans. Primitive rope bridges (9a) were used since the beginning of civilization. Early explorers traveling in Asia reported about impressive Chinese suspension bridges (4b). In Europe, suspension war bridges were built in the 16th century while permanent iron chain suspension bridges were introduced about 1740. Telford's bridge across the Menai Straits (9b) with a main span of 174 m was completed in 1826.

Most modern suspension bridge development has been done in the United States. The pioneer work by the Roeblings in the Niagara Falls Bridge and the Brooklyn Bridge (9c) finished in 1854 and 1883 started a new epoch, which culminated in the Verrazano-Narrows Bridge with a span width of 1298

a. 

b 

c. 

d. 

e. 

Figure 9 Suspension bridges a. Rope Bridge Ivory Coast b. Manai Suspension Bridge (GB 1826) c, Brooklyn Bridge (USA 1883), d. Humber bridge (GB 1981) e Seto Ohashi-Bridges Japan 1988.

At present (2001) large European and Japanese suspension bridges have been built (9e).

2.9 Cable-stayed bridges

Cable-stayed bridges are competitive for road bridges with span widths of 200-500 m. With respect to span widths they fill the gap between the suspension bridges and large prestressed concrete bridges or steel plate girder bridges.

a. 

b. 

Figure 10 Cable stayed bridges a Penang Bridge, Malaysia, b. Ponte da Vasco da Gama. Portuagal (1998)

2.10 Concrete bridges

Although hydraulic concrete was used by the ancient Romans, knowledge of the material was lost from the fall of the Roman Empire until the middle of 18th century. Its revival as a structural material depended on the development of hydraulic cement which began unsystematically around 1750. A decisive step came in 1824, when Aspdin began the manufacture of Portland cement. By 1830, concrete, consisting of a mixture of cement, sand, gravel and water, was fairly common in the foundations of bridges and harbor works. The Moniers patent of reinforced concrete was dated 1867.

Concrete arch bridges (11a,b) arose as an engineered system of construction during the last quarter of the 19th century, and from the early 20th century reinforced concrete was used for road and railway bridges. In 1912 the span width of concrete arches was above 100 m. Reinforced concrete theory was developed and used in bridge design.

Reinforced concrete was competitive for small and large bridges. We find bridge structures like plates, beams and frames (11c,d). Introduction of prestressed concrete from about 1927 gave new possibilities of modern bridge design. The span widths became larger and rational building and production systems have been developed. Development in concrete material design during the last decade has allowed progress concerning strength and durability.

a. 

b 

c. 

d. 

e. 

f. 

Figure 11 Concrete bridges. a. Stone and concrete arch, b. concrete arch. c.d Reinforced concrete beam bridges e.Oosterschelde Bridge (Netherlands 1965) f Øland bridge (Sweden 1972)

2.11 Bridge failures

There have been failures of bridges during the history. They have been caused either by environmental forces (12a), by wind, waves and torrent, too bold design, material failure, wrong analysis, or bad manufacturing or construction. Accidents, such as ship collisions, and war actions may also have destroyed bridge structures.

The collapse of Tacoma Narrows Bridge due to wind turbulence is perhaps the best-known bridge failure the last half century. 77 people died at the failure of the Tay Bridge in Scotland 1879, and during the building period of the Quebec Bridge 95 persons were lost. Recently historical bridges as the Stari Most bridge (5c) and other bridges (12b) in Yugoslavia were destroyed by war actions.

Figure 12 Bridge failures a. damage by nature. b. damage by war actions.

3 TRENDS IN BRIDGE DESIGN

3.1 The design process

Bridges primarily serve a functional purpose. They are supposed to provide continuity across gaps along transport routes. However, other requirements have also to be set to bridges. The most important of these are the safety aspects, functional ability, feasibility, durability, economy and elegance.

A classification of bridges is often made with respect to the user of the bridge, the material which has been used, the static system, the geometry. the construction method used or service life. Examples of bridge types are given Figure 13.

Figure 13 Examples of bridge types. a. Road bridge, b. Train bridge, c. Concrete bridge, d. Steel frame bridge and floatong bridge. (in front) e. Ganter bridge (Switzerland 1980) f. Alamillo Bridge (Spain 1992) g. Concrete truss bridge e h. Moving bridge. i. Normandy bridge (France 1994)

Technological developments have provided us with new possibilities in bridge design. Previous limitations in respect of dimensions and spans widths are being exceeded, and bridge history bears witness to examples of quantum leaps. New technology has led to high degree of specialising and automating in the design and building process which require special quality assurance procedures.

Regulations relating to the environment and the requirements to finances and rational design have however been tightened up. We have examples of bridge design where the demands in respect of function and finances have dominated planning. The result was that the aesthetic aspects were pushed into the background. Trends indicate however the importance to preserve the interaction between the environment and human intervention. Aesthetics in bridge design as also the protection of historical roads and bridges have therefore appeared on the agenda.

3.2 Bridges during construction

Different types of construction methods have been developed. Stone and concrete bridges have to be built on scaffolding, while steel bridges are manufactured and put together on site. Free cantilever building methods for steel and concrete bridges have bee developed. Bridges have been pushed and floated into the right position, and installation techniques have been worked out for prefabricated bridge elements. Examples of bridges under construction are given in Figure 14.

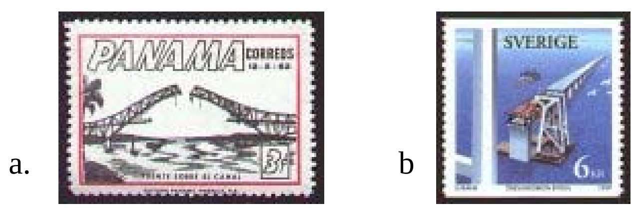

Figure 14 Bridges during construction a Thacher Ferry Bridge (Panama 1962) , b. Øresund bridge (Sweden- Denmark 2000)

3.3 Milestones in bridge design

New technology is breaking barriers. The period, during which the roads and rail networks were built at the end of the 18the century, was technologically important for bridge building. New materials and methods of analysis appeared during the middle of the 18th century adding new dimensions to the structures built. The Forth Bridge, built of steel in 1889, with its 517 m span, is an example of a “quantum leap” in building technology in respect of dimensions.

Former assumed barriers are falling in the face of current developments in respect of computers and technology linked with materials science. Examples of this are to be found in several types of bridges.

The Humber Bridge in Britain (1981) (9d), with its longest span of 1,410 m, used to be the longest suspension bridge in the world. It was recently surpassed by the Storebelt Bridge in Denmark (1998), with its longest span of 1624 m, and the Akashi Kaikyo Bridge in Japan, (1998) with a main span of 1990 m.

The cable-stayed bridges, Normandy Bridge in France (13i), completed in 1994, and the Tatara Bridge Japan, completed in 1999 extended the limits for this type of bridge to 856 m. respective 890 meters. Until then this type of bridges was competitive for road bridges with span widths of 200-500 m.

Concrete arched bridges have been built with spans of up 390 and 420 meters, such as the Krk-Rijeka Bridge in Croatia (1977) and Wanxian Bridge China (1997).

The spans of steel arched bridges, like the New River George Bridge in West Virginia, USA (1977), have reached 518 m. Steel plate and box girder bridges, such as the Niteroi Bridge (1974) near Rio de Janeiro, Brazil, span 300 m.

Norwegian bridges, like the Rafsundet Bridge and the Stolmansundet Bridge, have in year (1998) extended the spans of concrete girder bridges up to and in excess of the 300 m limit.

The challenges by the present day bridge design are not to exceed the longest span, but to exploit technology from a technical and economic perspective in order to build functionally correct bridges in harmony with their surroundings.

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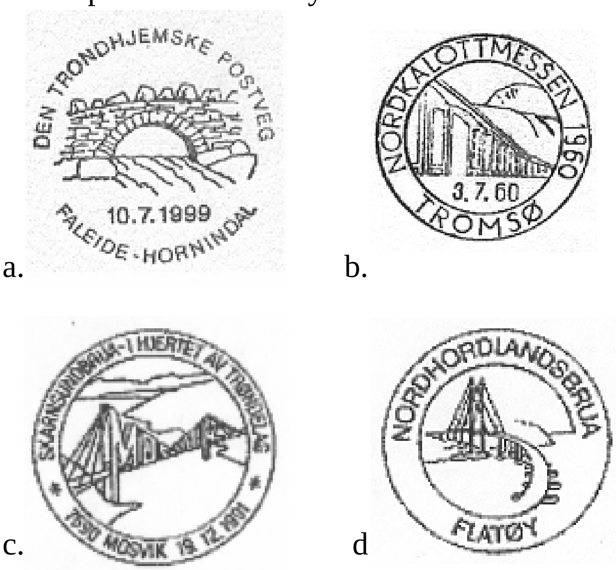
4 NORWEGIAN BRIDGE BUILDING

The oldest known Norwegian bridge was the Hjallar Bridge, a stone bridge dating from around the year 900 AD, but which was unfortunately pulled down in 1898. However, “Smedbrua” in the county of Buskerud, which was built in 1624, is currently the oldest existing Norwegian bridge. The silver mining activities at Kongsberg required far better roads that those which existed in Norway at that time. The bridge could be used by horses and carts, and even today it serves as an active part of the road network. In 1960 the Ministry of Roads served a preservation order on the bridge, thus preserving for posterity an expression of good engineering art coupled with solid Norwegian masonry traditions.

Thereafter and up until the beginning of the 19th century, most of the bridges built were simple timber and stone structures (15a). The need for bridges came with an increase in road building activities, which were based on the road statutes passed in 1824 and 1851. (16a). Impulses acquired from European bridge design were transferred to bridge developments in Norway.



a. b. c. d

Figure 15 Norwegian bridge post stamps. a. Old stone bridge. b. Tromsø Bridge (1960), c. Skarnsundet cable stayed bridge (1991), Nordhordaland floating and cable stayed bridges (1994)

Wooden bridges with span widths of about 35-40 m were built in the 1840s. At the same time chain suspension bridges with spans in excess of 50 m were constructed. Steel truss bridges, which were more than 100 m long, were introduced in 1889. Since the first years of the 19th century the usual types of smaller bridges were reinforced concrete slabs and rolled steel beams with concrete bridge decks.

Between World Wars I and II, a number of bridges were built as stone arches, steel trusses, concrete beams and arches. The Kylling Bridge (16c) at the railroad Rauma Line (1915-24) is a typical representative of the type of stone arched bridges which were built for the Norwegian State Railways and the Public Roads Administration after the turn of the century and up until the middle of the 1930s. Some suspension bridges were also built. The Fylkesund suspension bridge of 1937 has a span with of 237m, while the Askøy bridge build in 1992 (16f) has a span width of 850 metres.

Prestressed concrete was introduced to Norwegian bridges in 1950, and the Tromsø Bridge from 1960 (15b) was the first concrete bridge structure built in Norway using the free cantilever method.

During the period 1960-1980, there was an increase in bridge building activities. The free cantilever concrete beam bridge was a competitive and frequently used type used across the Norwegian fjords, Typical example from this period is the Herøy bridge (16e) build in 1976 with a span width of 170 metres.

Figure 16 Norwegian bridge building, a. Need for bridges. Ferries were used to cross water. b Military floating bridges, c. Kylling bridge d.. Symbolic bridge European community. e.. Herøy bridge (1976) f. Askøy bridge. (1992)

Major bridge design challenges during the 1990s and up to date consisted of the construction of "free cantilever" bridges, suspension bridges, cable-stayed bridges and floating bridges. Feasible submerged floating tunnels across Norway's fjords have also been planned.

A few examples of selected Norwegian bridges may serve to illustrate development in Norwegian bridge engineering.

The Skarsund Bridge. (15c) in the county of Northern Trøndelag, a cable stayed bridge, was setting in 1991 the world record for this type of bridge with a span width of 530 m.

The Bergøysund Bridge (1992) in the county of Møre and Romsdal was the first modern floating bridge to be built in Norway. It has an arched outline, with a total length of 931 m divided into 10 spans. The North Hordaland Bridge, (15d) built in 1994, is however Norway's other large floating bridge. It has a total length of 1610 m

In 1998 the Rafsundet Bridge in Nordland and the Stolmasundet Bridge (1998) in Hordaland were built They represent milestones in concrete bridge design, approaching spans of 300 m.

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