Presenting Construction History in museums: Bridges in the German Straßenmuseum Germersheim

Eberhard Pelke

The German Straßenmuseum Germersheim (Fig. 1) was founded in 1989 and included in the list of German museums as a specialized technical museum in 1995. The objective pursued is to promote the interest in the history and significance of transport and road engineering in Germany and to keep up further scientific research into that subject. Based on the three phases in the life of a street, namely planning, construction and use, the layman is given an overview of the tasks to be performed in transport and road engineering, while the engineer is reminded of the history of his/her field of work and given an outlook over recent developments.

Figure 1
General view on the Dt. Straßenmuseum Germersheim
(Photo: Dt. Straßenmuseum Germersheim)

The German Straßenmuseum Germersheim was started around 1987 by a small group of engineers of the roads department of Rhineland-Palatinate. Because there was initially no government funding, a registered society undertook the sponsorship. The lack of funds forced the museum society, to concentrate at first on building up a solid base of members — in addition to personal members mainly legal entities (associations, administrations, industry). The commitment of the city of Germersheim, as well as of the state of Rhineland-Palatinate, meant that in 1993, and in a second stage of construction in 1996, the museum could move into the freshly renovated armory in Germersheim, in the end gaining 3,000 m² indoor space and about 2,000 m² open-air exhibit ground.

Subdivided into the departments of road design, survey, land conservation and design of roadside environment, road construction, structural engineering, highway operations and road maintenance, road equipment, vehicles, machinery and equipment, the German Straßenmuseum presents the visitors with the historical context with the help of numerous exhibits, as well as allowing them to experience technological developments.

In addition to the museum section, the sponsor feels it is important to support research into technical history through an academic department and the
gradual creation of a specialist library. Rooms for lectures and training and further education courses, as well as a Cafeteria round off the picture. Evacuated exhibits are kept in rented warehouses.

The board of the registered society is supported by the competent specialists of a committee and an academic commission. The committee consists of highly qualified men and women from the administration and the business world. The academic commission advises the board in questions of the overall concept, didactics, method and visitor research.

The separate exhibition areas are technically and structurally worked out and realized by unpaid specialist advisors. These specialist advisors are integrated into the museum society through the full-time academic department and a permanent coordinator on the board.

At the moment there are eight specialist advisors in the areas of highway operations, design, structural engineering, road construction, history, traffic, road construction machinery, and road planning.

The museum has about 1,000 legal and natural members. The number visitor per year lies between 10,000 and 15,000.

DEPARTMENT OF STRUCTURAL ENGINEERING

In the department of «Structural Engineering» the development of bridges had to be dealt with.

The armory’s massive walls helped in dividing the part of the exhibition situated in the west wing into themes, so called theme boxes. The visitor entering the department of «Structural Engineering» is greeted by two life-sized cross-sections of tunnels in the process of being built. In comparing the light cross-section of the modern New Austrian Method of Construction (NÖT) with that of the 19th century, completely blocked by wooden supports, one can intuitively feel the high level of mechanization and the progress in structural engineering that lies between the two (Fig. 2). The visitors begin their tour with the history of bridges and the area «Statics and Stability», designed by Prof. Dr.-Ing. W. Ramm (Fig. 3). Then there is steel making and steel girder construction (Fig. 4). The mechanization of construction methods with the main types of scaffolding lead to the box on prestressing techniques (Fig. 5) and to the history of reinforced and prestressed concrete (Fig. 6). Short introductions to the bearing of bridges and their expansion joint as well as geotechnics with an emphasis on foundation are rounded off with design and construction of engineering structures. The last two boxes are dedicated to the phases of use of a building. The necessary rehabilitation and maintenance measures, and the continuous supervision to ensure the traffic safety and stability of buildings are described; an official bridge inspection. The museum was able to win a qualified expert from the relevant field of site
GUIDELINES AND CONCEPTION FOR PRESENTING THE HISTORY OF BRIDGES IN MUSEUMS

The guidelines can be separated into those relating to museum didactics, and those relating to questions of transport and construction history.

Museum didactics

To guide the visitors, and give them the chance to process the information at leisure, the exhibition section’s structure and design must be subordinate to the concept of the museum as a whole. The exhibition section has traditionally been designed in panel form. The presentation of every bridge is fourfold: The year of its opening to traffic, a contemporary depiction with a subtitle giving the bridge’s name, and up to three technical data depending on the type of bridge (max. span l, rise to span ratio, sag ratio f/l, slenderness ratio of stiffening beam v/l), a short text and a portrait of the leading engineer. A graphical panel illustrates the type of bridge and technical data.

Every bridge makes the connection to a technical innovation. The point, however, is not to acknowledge solitary technical milestones, but to illustrate lines of development, which help the visitor to understand today’s construction of bridges. The combination of date, contemporary depiction, portrait and short text goes beyond mere transportation of facts and engages the visitors’ interest in the building; tells them a little story. The technical begins to interweave with the personal. I refer for example to the deadly accident Albert Gisclard (1844–1909) had with the test train only a few before the official opening of his cable-stayed bridge anchored in the ground near Cassagne (1909) and the courageous jump of his pupil Gaston Leinekugel le Coq (1867–1965) from that same test train. Leinekugel le Coq developed Gisclard’s system further, as can be seen in the bridge in Lézardrieux (1924). The portrait of the leading engineer of a given bridge, always accompanied by dates of birth and death, has over time turned out to be indispensable. Especially the
older portraits illustrate the diversity of the designing building engineers’ different character and personality. They release the building from its anonymity and, together with the text, enable the visitors to gain a very personal access to the building and the engineering profession.

The exhibition does not force information on the visitors, but gives them space to make their own observations, draw their own conclusions. The observations and conclusions awaken the visitors’ interest in bridge construction. The many bridges shown—divided into the four basic types of girder or beam bridges, vault and arch bridges, suspension bridges and cable-stayed bridges—lead the visitors to the three principal stresses on the construction: tension, compression and bending. If they want to expand their knowledge beyond the appearance of the bridge, the illustration, and find the transition from structural constructions to structural systems, then they can continue the exhibition through “Statics and Stability,” where they can work out the interaction between the “History of the Bridge” and the mathematical-physical models explaining the flow of forces in structural construction. This part of the exhibition leaves the emotional level and shows the technical facts.

**CONSTRUCTION HISTORY GUIDELINES**

The construction history guidelines as a list of propositions:

— Individual, society and building are connected.
— The building of bridges is connected to the decision by society to create and maintain an intact infrastructure.
— Bridges are a complex detail of the road as a whole.
— Bridges presuppose the will to trade (transport of goods), to exchange information (transport of people), and to gain military strength.
— Because the design of bridges is subordinate to the flow of forces according to the rules of mathematics and physics, the architect cannot create a solitary building, reflecting its designer and builder in person and program.
— The first bridges were not made of stone but of wood.
— Architectural thinking, based on the experience of trial and error, ties the design of bridges to a few forms.
— In the ancient building of vault bridges, the focus must be taken from the Romans and broadened to include the Chinese builders.
— The complexity of their construction meant that no beam bridges were successfully finished until about 1800 AD.
— The diversity of forms, the development of a design palette, has its roots in systematic observation (trial and error) and the development of mathematical-physical models for construction.
— The beginning belongs to the inventors, the development to science. The engineering profession grew out of people from other fields, tinkers and inventors. Only in a second step did the success of way of building become connected to systematic engineering research.
— Technical development begins in obscurity. Small buildings are technical milestones, big buildings are masterworks, the culmination of years of research.
— Beam bridges close the circle of the development of engineer bridges.
— Cable-stayed bridges show the interaction between scientific support and the success of a bridge design.
— Statics and steel allows dematerialization.
— The absence of suitable iron-ore and ironware supported the dematerialization of structural constructions in Germany.
— This dematerialization shows the way from the beam to the arch.
— Iron and steel forced the transition from the thrust line to the elastic arch and freed architecture from the painful discussion over an adequate vault theory. Adequate parts for the realization of the deflection of the bridge were quickly found.
— Being prestressed frees the concrete of the force to bend and leads to the beam.
— Appearance and construction of bridges reflect developments in society. The paradigm shift from the priority of materials to a priority of the work forces a reduction of forms. «Mass thinking,» as a result of, among other things, a strict interpretation of the economic liberalism.
of the 19th century, shows filigree, dissolved frame work structures closely following the rules of statics. The emergence of the labor movement, the gradual introduction of social security systems and adequate wage settlements lead to an investment in mass, and a reduction of wage costs. Rational ways of building, together with a Zeitgeist which longed for quiet forms, meant that the palette of forms grew poorer, focusing the design of bridges on a few successful types, and ending in today’s discussion over a building culture in bridge design.4,5

THE HISTORY OF BRIDGES

The simple, chronological subdivision into three main areas, i.e.

1. Bridges of the ancient world and before
2. Construction of bridges in post-Roman times and bridges in the Middle Ages
3. Construction of bridges from 1750, with the emergence of engineers shows the visitor the close link between bridge construction and the needs of military and trade.

Area I: Wood and stone bridges of the ancient world (up to about 400 AD)

Area I presents the earliest important types of bridges. On the horizontal line, four types of bridges are presented: the wood and stone beam,6,7 the Roman semicircular arch and the Chinese arch bridges.9,10 Time is shown on the vertical line. This concept of presentation helps visitors to realize that after finding the structural construction, further development took place only in small steps, on the basis of experience. At the end of the line, there is the bridge of Anji, pointing into the future, past area II. With the bridge over the Pyratal in the Vogtland (Germany), the visitor discovers the same bridge construction as the final stage and highlight of vault construction about 1400 years later.11 On the panel of the Roman semicircular arch bridge, visitors can see that after the development of the arch by the Etruscans, and the invention of cement mortar by Roman architects, the scale may have changed, but the technique did not change significantly.

Area II: Construction of Bridges in the Middle Ages (about 400–1200 AD)

Area II shows, already through its inverse coloring, the decline in the art of bridge building between 400 and 1200 AD as a result of lacking demands on the infrastructure. The revival of the Roman art of the vault by «Bauhütten» and monks is spotlighted.

Area III: The Time of the Engineers (from 1750)

In area III, visitors experiences a time of change, from the builder, craftsman to the engineer thinking in terms of mathematical-physical models. The coordinate system topples. Horizontally, visitors move along a timeline from 1750 to today. Vertically, four basic structural constructions develop:

1. Girder or beam bridges (principal stress: bending)
2. From the vault to the elastic arch bridge (principal stress: compression)
3. Suspension bridges (principal stress: tension)
4. Cable-stayed bridges (principal stress: compression / tension)

The simple arrangement of chronological order and main structural system let visitors discover essential chains of development themselves: Two of these developments are give here as examples:

From the Beam to the Arch

The bridges of the Grubenmann family (Fig. 7), a family of carpenters, are the result of years of building experience.12 The mixture of arches, truss and frame work indicates an intuitive approach to large span constructions, but also a lack of knowledge about the flow of forces. The Grubenmann’s craftsmanship lacked the tools of the engineer. It doesn’t admit a clear assignment of force and load bearing member. The beam awaited its engineering instrument in Navier’s Elastic Theory (1826). The legendary inventor of the locomotive and railway consultant George Stephenson (1781–1848) was the
first to succeed in a clear assignment of bending tension and bending pressure with the Gauntless-Viadukt (1825) (Fig. 8), a probably an experimental building realized in the course of the world’s first railway from Stockton to Darlington.\textsuperscript{11} The missing shear rigidity was delivered by the Hanoverian architect Georg Friedrich Laves (Fig. 9)\textsuperscript{14} The missing understanding of the fishbelly girder suitable for engineers was supplied by Friedrich August von Pauli (1802–1882). He turned Laves’ System into a clear, strong system, suitable for heavy loads (Fig. 10), which he could also describe mathematically-physically.\textsuperscript{15}

The pressure to create a road network throughout the USA using unskilled labor, without an infrastructure, dependent on materials available on site, resulted in classical architect Ithiel Town (1784–1844) and US army general Stephen Harriman Long (1784–1864) inventing parallel boomed wooden beams, the lattice work (Fig. 11), which could be assembled easily and quickly.\textsuperscript{16} William Howe (1803–1852) improved Town’s deficient design of
joints, without being able to significantly increase the constructions’ life. The sound politechnical education of the mill-owner’s son Squire Whipple (1804–1888), was necessary to move beyond lattice work, which probably went back to the craftsmanship of the Grubenmann family, and had probably been introduced to America by James Wernag, a native of Rietlingen. Squire Whipple, with his patent for «Bowstring» bridge beams (1841) and his instruction book «A Work on Building Bridges» (1847), began bridge design by engineers in the USA (Fig. 12).

Hermann Lohse (1815–1893), Carl Lentze (1801–1883) and other German travelers to England and America, saw the lattice work, and not Whipple, as the decisive impulse. They succeeded in dissolving the parallel boomed iron plate girder in the bearing wall, thereby significantly improving Robert Stephenson’s (1803–1859) Britannia bridge, but this German ‘special way’ had already crossed its zenith after 10 years, with the lattice work bridge at Waldshut (1859) and the Rheinbrücke Kehl (1861) (Fig. 13). Several successors were not able to do away with the system’s disadvantages of high use of mass, caused by the parallel girders, and the problematic buckling of the lattice work bridge at the bearing.

The paradigm brought home by those who had traveled England and America forced German bridge design to find the way to frame work constructions via the lattice work girder (Fig. 14).

The first iron viaducts in France’s Massive Central already show the finished development of the parallel boomed frame work. Gustave Eiffel (1832–1923), chemical engineer and genius at simplifying constructions in the course of four years overcame the lattice work (La Bouble Viadukt) and found in the La Sioule Viadukt the real frame work construction, enabling him to manufacture and assemble in a way suitable for iron (Fig. 15).
In the race with von Pauli for the minimal use of Mass in railway bridges, Friedrich Wilhelm Schwedler (1823–1894), with the help of his analytical theory of frame work construction, found the way back to Whipple’s Bowstring bridge. Schwedler depended not only on the theory of the flow of forces for minimizing mass, he also optimized constructive detailing and supported manufacturing best suitable to iron. In the Weserbrücke at Corvey (Höxter), 1864, the standard of Prussian bridge construction was reached, the statically determinate "Schwedlerträger".

Figure 13
Hermann Lohse (1815–1893): Eisenbahn-und Straßenbrücke über den Rhein bei Köln (Dombrücke) $l = 103.2$ m, 1859
(Photo: Trautz, Martin: Eiserne Brücken im 19. Jahrhundert in Deutschland, page 68)

Figure 14
Van Diesen and L. A. Rouppe van der Voort (design) and Brückenbau-Anstalt Harkort (contractor): Lekbrücke bei Kuilenburg $l = 157.3$ m, 1868
(Photo: Stein, P: 100 Jahre GHH Brückenbau, page 51)

Figure 15
Gustave Eiffel (1832–1923): Viaduct de La Sioule $l = 57.8$ m, 1869
(Loyrette, H.: Gustave Eiffel-Ein Ingenieur und sein Werk, page 54)

Figure 16
Johann Wilhelm Schwedler (1823–1894): Weserbrücke bei Hoexter (Corvey) $l = 56.4$ m, 1864
(Hertwig, A.: Leben und Schaffen der Reichsbahn-Brückenbauer Schwedler, Zimmermann, Labes, Schaper, page 17)
Heinrich Gerber (1823–1912), pupil of von Paulis and building site manager for the great Pauli girder bridges at Grosshesselohe and Mainz, overcame the corset of static rules by fixing the centre of moments. His road bridge over the river main at Haßfurt (1867) flawlessly shows the flow of forces in the continuous girder and makes the changing play of forces transcendent through changing intersections of the curved girder (Fig. 17).

The Elbebrücke (1872, 1888) by Hermann Lohse (1815–1893) stands at the end of the dematerialization through girders. By assigning the girders flexural rigidity and through the arrangement of the inserted suspender, Lohse nearly gets rid of the bearing walls (Fig. 18). While the girder statically is a combination between compression and tension arch, the German name «Träger» is based on the definition as transferring the load only vertically to the substructure. Because of their statically indetermination and their vulnerability to restraint forces, the solitary «Lohse Girder», while popular with the people, remained disputed among experts.

While Johann Andreas Schubert (1808–1870) had splendidly discussed the right theory of the vault using the building of the Götschtalbrücke (1851), Emil Hermann Hartwich (1801–1879) already used the theory of elasticity for the first time in Germany to calculate the arch when he designed the «Alte Rheinbrücke Coblenz» (1864). The bohemian engineer Josef Langer (1816–?) already led the way by combining arches and girders to a highly efficient system. Langer’s system, the arch-supported beam, which is still used in bridges today, uses the compression rigidity of the arch with symmetrical loads, and skillfully transfers the load of traffic onto the bending resistant trussed beam (Fig. 19). The fusion of horizontal thrust and deck allows Langer’s girder to transfer only vertical forces to the foundation, making it universally usable, unlike the normal arch. About two decades had to pass until Langer’s girder, with the help of Johann Emanuel Brik (1842–1925), could realize this system in the Ferdinandsbrücke over the
Mur at Graz (1881). Langer's idea, and the still present necessity to save costs on materials, led the «Brückenausbauanstalt» Harkort under Johann Caspar Harkort VI (1817–1896), in their search for a successor to Schwedler's unit construction bridge system, to the arch with tieback. Harkort's arched girder without horizontal thrust (Fig. 20), unlike Langer's arch-supported beam, transfers the load to the bending resistant arch. The source of this was partly the trend prevalent then to separate road and main structural construction in order to avoid secondary stress, but probably also in the need to find a manufacturable system which can be used with a wider span. The road bridge over the Mosel at Trabach (1899) started the triumph of the bridge system outwardly controlled by statics, which reached its zenith in the Hohenzollernbrücke (1911) over the Rhein with a span of \( L = 167.8 \text{ m} \). Lang's girder and Harkort's arched girder without horizontal thrust were extreme cases between which today's arch bridges are optimized. By transferring the secondary stress to the bending and using compression as principal stress, they cross the line to the arch and at the same time form the end of the dematerialization of the bending beam.

In 1897, the Belgian engineer Arthur Vierendeel (1852–1940) is hired to develop the girder of the future for the occasion of the world exhibition in Paris in 1900. His attempt to find it is represented by the frame girder of Tervueren. The paradigm shift from efficient use of materials to wage efficiency, as a result of a more confident workforce, lets Vierendeel avoid completely breaking the bending down into compression and tension parts, limiting himself to horizontal girders and vertical frame struts, which he connects via bending resistant frame corner (Fig. 21).
The investment in materials is supported by the turn of the century Zeitgeist, which is looking for calmer forms and wants to let go of the nervous frame work constructions. Virendeel’s frame girder still stands, like a symbol, among filegree dissolving frame worked girders and arches, which even the reinforced concrete couldn’t resist.

Supported by the new, better quality steel grade and the new assembly technique of welding, the girder succeeds in step by step achieving a wider span. The Mangfallbrücke in the course of the German Autobahn A 8 (Fig. 22) forms the end of a development which puts the arch, despite its efficient use of materials, on the sidelines. While the problems of welding and buckling of the high web plate may not have been completely mastered in 1936, the Mangfallbrücke has the look of many present day girder bridges, which are however no longer dominated by steal but by prestressed concrete (Fig. 23).

Prestressing shows concrete the way from arch to beam
In the road bridge over the Dordogne at Souillac (1822) Louis Vicat (1786–1861), engineer Ponts et Chaussées, used artificial limes for the first time. For a rediscovery of concrete, the adition of gravel or stone chippings was needed. This was done by the architect François Martin Lebrun (?–1849) around 1840 in the building of his vault bridge Pont à Grisolles. Both vault bridges were barely noticed; singular works. As is nearly normal in the early history of concrete, it was again a layman, the entrepreneur and son of a matchstick manufacturer François Coignet (1814–1888), who built the first succesfull arch bridges with his béton agglomérés. The structural construction of the drinking water aqueduct in the forest of Fontainebleau (Fig. 24), built from tamped concrete without reinforcement,
clumsily followed the thrust line, like a stone bridge. Only 10 years later, the governmental builder Matthias Koenen (1849–1924) created the first theory for measuring reinforced concrete. Daring and trust in the bending capacity created through reinforcement characterize his road bridge at Wildegg (1890) (Fig. 25). The first successful arch bridge made from reinforced concrete, based on the system of Joseph Melan (1853–1941), was similarly slim, with an iron frame work reinforcement (Fig. 26). François Hennebique (1842–1921) gave reinforced concrete its identity. Hennebique’s reinforced concrete bridges all followed the principle of monolithically connecting rib and plate, as the Pont sur la Vienne de Châtellerault (1899) shows (Fig. 27). The initial tendencies towards daring (f/f) were finally corrected by Emil Morsch (1872–1950). In his Isarbrücke at Grünwald (1904) and the Gmündertobelbrücke (1908), a serious rival has been created for steel (Fig. 28). Shocked by his own success, concrete begins to copy steep. (Fig. 29).

In the extreme deflection of the vertex (1912) of the Pont de Le Veudre sur l’Allier (1910), Eugène Freyssinet recognized the non-elastic deformation habits of concrete and the necessity of using steel to prestress the concrete. Interrupted by World War I and ongoing projects, Freyssinet used the Great Depression from 1926 to 1929 to develop all important components for the prestressing of concrete. With the prestressing tendon lying in the concrete, following the thrust line, Freyssinet freed the concrete from the necessity to form an arch and gave
it its form from the beginning (Fig. 31). Prestressed concrete found its way to Germany via Prof. Dr. Karl Mautner, member of the board of the Wayss & Freytag A.G. Germany thanked him in its own way.

In the race against Freyssinet, Franz Dischinger, working for Dyckerhoff & Widmann, at the same time found the way to the underspanned bending girder via the reproduction of Harkort’s girder in concrete (Fig. 30). Around 1990, Friedrich Staafuß came back to the prestressed bending girder with external deflected tendons, and caused externally prestressed concrete box girder bridge to be developed into the standard way of building bridges spanning over about 40 m. The direct relation to Dischinger's road bridge in Aue (1936) is evident. The stringent limits set by the parallel boomed T-beams or box girder begin to dissolve under the aim of flexible adaptation to the intended use and cost-effective maintenance. Have the structural constructions of bridges come full circle?

SUMMARY

Engineers are men without history: Fixed on the new, forgetting the old. That is the mirror usually held up to us engineers, or even worse: the image we are proud of. Why, then, a history of site engineering in the context of ongoing projects? History of site engineering doesn’t exist for its own sake. It makes it possible to assess future developments, or recycle solutions from the collection of our predecessors, and to add the missing link to make an old idea work. An awareness of history helps avoid doing the same thing twice, and is a source for ideas.

An interaction of history of site engineering and the development of modern society is necessary. It explains important technical developments, or their lack. In the interest of completeness, especially in the areas of road and bridge building, this second step is necessary.

There is an intact community of interested laymen and experts in site engineering. I have a lot to thank them for. My thanks are especially due to Dr. K. Stiglat, Prof. von Wölfel and his illustrator Prof. K. Nerlich, and many colleagues especially from other countries who spontaneously helped the cause.

What is still missing is an effect on the outside.
Instead, the history of site engineering becomes a fashion propagated by laymen who don't know engineering history, who use it for their own ends without acknowledging the leading function the flow of forces has in design.

REFERENCE LIST


