

MODERNITY IS A NEW TRADITION – SUSPENSION BRIDGES

NOWOCZESNOŚĆ TO NOWA TRADYCJA – MOSTY WISZĄCE

Abstract

According to Zvi Hecker „*tradition is a living continuity composed of layers of discovery ideas following each other. [...] The layers of original concepts, acts of discovery form our tradition. [...] Our contemporary ideas are always rooted in the past; it is not well defined and as such remains open to a new interpretation.*”²

„Modernity architecture means the existence beyond tradition and the past”.. however the first, model used to be in essence so precursory so that tend to be so modern.. are useful.. for the future... Suspension bridges built many years ago are still perceived as “original, technologically advanced. They are the realization of rationality. They assume the primacy of reason”. They form the synonym of modernity: purposefulness and the logic of construct – as the requirement of economic reason and intent of the constructor – defeating large spans. They are one of a few forms of architecture which up to our times has not left the mystery and the power of stimulation of imagination.

Keywords: suspension bridges, string structures, architectural form, tradition, modernity

Streszczenie

Według Zvi Heckera „tradycja jest żywą ciągłością, składa się z następujących po sobie pokładów odkrywczych idei. [...] Pokłady oryginalnych koncepcji, odkrywczycy akty twórcze tworzą naszą tradycję. [...] Nasze współczesne idee są zawsze zakorzenione w przeszłości, nie jest ona jednak nigdy ściśle zdefiniowana i przez to pozostaje otwarta na nową interpretację”².

„Nowoczesność architektury oznacza istnienie poza tradycją, poza przeszłością”... jednakże obiekty pierwsze, wzorcowe bywają na wskroś tak prekursorskie, iż nadal wydają się być nowoczesne... są użyteczne... dla przyszłości... Mosty wiszące powstałe wiele lat temu wciąż postrzegamy jako „oryginalne, zaawansowane technologicznie, są realizacją racjonalizmu, zakładają prymat rozumu”. Stanowią synonim nowoczesności: celowości i logiki dzieła – jako wymóg ekonomiczności i zamierzenia twórcy – pokonywania wielkich rozpiętości. Pozostały, jedną z nielicznych form architektury, która do obecnych czasów nie utraciła tajemnicy i mocy pobudzania wyobraźni.

Słowa kluczowe: mosty wiszące, konstrukcje cięgnowe, forma architektoniczna, tradycja, nowoczesność

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² Z. Hecker *Architektura i tradycja*, (transl. M.A. Urbańska), Architektura & Biznes, 1996, no. 1, p. 14.

1. PRELIMINARIES

The history of development of bridges realized on a basis of string construction has a long history. Dating back to ancient times, crossing over obstacles were built with the use of strings. Building materials as well as some references were the artefacts of the Nature. The twists of climbers hanged over obstacles gave rise to suspension bridges. Over time climber were replaced by ropes composed of floral fibres and in the sequel by chain and steel wires. In primitive constructions were used footbridges composed of parallel strings hanged as pairs at different levels and connected crosswise to maintain a suitable distance. The form of these constructions was simple and transparent. The shape of lines and a distribution of force existing there were easily comprehended through associations with shapes existing in the Nature.

The idea to support beams with the aid of oblique strings being used in contemporary cable-stayed structure originate from sailing boats used in ancient Egypt. The tangible period of the development of hanging systems was the use of medieval forged iron chains found in the construction of bridges such as drawbridge ones.

The cable-stayed bridges appeared in the 17th century. The first construct of this nature was the project designed by the Venetian Fausto Veranzio in 1617.³ A pair of vertical suspenders was placed in the middle of the deck (the load-bearing portion) and was suspended to strings spread over the towers. All others were leaned and their mounting resembles suspension bridges being present today.

In 1784 a German Carpenter Immanuel Loescher constructed a wooden bridge with deck hanging to tower with the aid of wooden oblique raking props. The next realization of the 18th century was the King's Meadow Bridge with a span of 34 meters designed by English engineers Redpath and Brown. The deck was suspended with wires to the cast-iron tower.

2. 19TH CENTURY

In the 19th century constructed were consecutive bridge constructs with cable-stayed structure. In 1821 developed was a single-span bridge designed by the French architect Poyet. The girders were attached to portal towers with the use of lines that were distributed in fan-like way. A remarkable undertaking for these times was also cable-stayed bridge designed by Hatley in 1840.⁴

However because of the collapse of such bridges, there was a small number of them built and the interest in such constructs was quite limited for a number of decades. There were several reasons behind the collapse of bridges: inability to deliver materials of high tensile strength and a lack of understanding of fatigue of material and its corrosion on the constructions.⁵

The bridges of suspension construction with link chain cables which were made of welded iron were started to be built at the beginning of the 20th century. Notably, in North America James Finley built the first suspension bridge in 1796 located over the Jacob Creek in Pennsyl-

³ Z. Wasiutyński, *O architekturze mostów*, Warszawa 1971, p. 424.

⁴ E. R. White, *Structural Aspects of Cable-stayed Bridge Design*, 1975, www.pdf.semanticscholar.org.

⁵ A. Adesiyun, A. Czerepak, L. Korusiewicz, L. Makarowski, A. Wysowski, *Badania systemów linowych stosowanych w konstrukcjach mostowych*, Inżynieria i Budownictwo, 2003, no. 3.

vania, however he received a patent for this design only in 1801.⁶ Until 1820 there were around 40 similar constructs nevertheless these bridges were not long. The longest hanging span in the world whose spread was as much as 176 meters was the engineering masterpiece of Thomas Telford located in Menai Straits in Wales. This bridge was spread over the banks of rocky and narrow strait. It was completed on August 9, 1825 by nailing the last symbolic rivet. The construct was one of the largest and the most impressive artifacts of these times being a symbol of the 19th century. Two years later Ignaz von Mitis completed a bridge over the Danube canal in Vienna – it was the second suspension steel bridge on the European continent. It is worth noting that France was the land of suspension bridges. It was found that in the period 1825–1842 constructed 147 constructs and 114 out of them were built in France.⁷

One cannot overlook achievements of the American engineer Johan August Roebling. In 1841 this talented designer developed an innovative way of constructing ropes of suspension bridges. Prior to this time the ropes were prepared in advance before starting the construction of the bridge. Roebling established and patented a way of forming large and strong cables made of thin individual rods coiled in a continuous ways on the construction site.

This fast, efficient and far cheaper method has opened in the bridge industry new possibilities – since then one could build bridges of far larger span and abilities to cross more difficult obstacles.⁸ The first modern artefact of Johan Roebling was the Grand Trunk Bridge (1855) – the largest suspension bridge of this time. It was constructed in the picturesque landscape in a close neighbourhood of the Niagara Falls and spread over the St. Laurence River. It was a genuine technical achievement however in opinion of designers not so successful artistic accomplishment. The set of vertical lashing cable connecting the lower deck of load-bearing structure with the rocks of the ground was quite heavily criticized as impacting visual features of this unique place.

The successive suspension bridges constructed by Roebling in Pittsburg (1860) and in Cincinnati (1867) over the Ohio River (328 meters) were a sort of a prerequisite of a unique masterpiece – the bridge over the East River in New York. By starting this project, Roebling collaborated with his son Washington August who was his successor. Unfortunately, Johan Roebling died during setting out support. The opening ceremony took place on May 24, 1883. In this way, the bridge became the largest suspension bridge in the world. Main span of the bridge has the length of 486 meters, side span 284.5 m and the width has 25 m. Towers are located 84 meters over the water level. Currently after 120 years the Brooklyn Bridge serves the public and standing as the testimony to the accomplishments of its constructors.

3. 20TH CENTURY

Over the 19th and 20th century, the Pole Rudolf Modrzejewski worked in the US. He delivered the most visible accomplishments in the bridge industry. He built almost 40 bridges over the largest rivers of the continent. Among others there were 6 bridges over the Mississippi River, Missouri, Delaware, Ohio, the Laurence River (Quebec), Big Lakes – Detroit (Ambassador Bridge), the bridge over San Francisco – Trans Bay Bridge. The bridge technology

⁶ J. Głomb, *Pontifex Maximus, Ponad przestrzenią i czasem*, Gliwice 1997, p. 160.

⁷ *Ibidem*, p. 119.

⁸ *Ibidem*, p. 160.

progressed in terms of spread boundaries, a modern approach to pylon – rope relation, the use of alloy steel and numerous design developments.⁹

At the beginning of the 20th century, in 1909 a spectacular bridge authored by Gustav Lindenthal was erected in New York. The Manhattan Bridge localized between the western Brooklyn and the south-west Manhattan. The steel towers of height of almost 100 meters keep four cables. The main span has a spread of 448 meters, side span are of length 221 meters.¹⁰ Pillars are composed of four columns bracing by horizontal beams and outer spaces are filled with cross links. The bridge has two levels where there are seven traffic lanes, 4 train tracks or pedestrian crossings. The lower level is positioned 42 meters over the water level.

The first half of the 20th century is a period of developments of suspended bridges of length of over 1000 meters. In the thirties, in the US built were two bridges of lengths not encountered so far, namely the Washington Bridge and the Golden Gate.

The large bridge over the Hudson River in New York opened in October 1931 and named after George Washington is the project of the well known engineer Othmar Ammann. The main span has the length of 1067 meters being the first bridge of length of over 1000 meters. The steel towers of height of 180 meters exhibit a lattice construction. Likewise deck was made of steel lattices. The bridge features four cables of diameters of 90 centimeters each. Each of them is composed of 27 thousand of wires whose total length exceed four times the diameter of the Earth. These wires absorb forces coming from 60 million of vehicles crossing the bridge every year. During the first 50 years of the existence, the bridge was crossed by over one billion of vehicles.¹¹ The expression of tensions in lines and suspender cables is consistent with the principle of completeness.

The Golden Gate Bridge located at the entry of the San Francisco Bay is localized in a unique surroundings of open ocean on one side and the bay with small isles on the other hand was opened in May 1937. The project of the bridge underwent many changes, primarily because of numerous suggestions and interventions from architects Irving and Gertrude Morrow. Irving Morrow was an architectural consultant in the team of Joseph Strauss who was the main engineer of the construction. Thanks to his abilities to combine art with design, the bridge gained a world recognition. Its length of 1280 meters was the largest in the world until 1964 (that is the year when the bridge over the strait of Verrazano in the state of New York was completed). Towers of height 227 meters were the highest in the world until 1998 until this record was beaten by the Akashi Bridge in Japan. The bridge is regarded as a superb accomplishment of engineering not only of this period. The architectural profile of the bridge painted in dark orange color has become a continuous inspiration of artists, painters, actors, and movie directors. Quite often fogs surround the bridge producing a unique and natural environment. It is impossible to imagine San Francisco without Golden Gate, which has become its part and a genuine symbol. Undoubtedly, we are dealing with the most characteristic and in this way the most recognized bridge in the world.

The object shows the beauty of simplicity of the engineering solution. Vertical frame pylon are the main accents of the composition of the bridge. Horizontal stiffeners over the bridge and cross-braces below the level of the road stress the unity of the structure of pillars being at the same time elements where one feels the existence of forces under their external forces. The

⁹ *Ibidem*, p. 185.

¹⁰ www.budowle.pl

¹¹ J. Głomb, *op. cit.*, p. 223.

arch profile of the deck exists in the three hanging spans and the span located on the access track stressing the unity of suspended structure and the unity of utility of the bridge. The dynamic character of carrying ropes perpetuated in concave lines is present owing to the play of forces preserve in their shape. The system of vertical suspenders – readable and rhythmic achieved through their density, generates open-work „walls”, namely the curtain of the road. Stiffening trussed construction of the deck not so visible in the scale of assumption, does not affect the order because their reverse inclination of raking props. The intensive colour of the bridge stresses its profile within the entire landscape. It has been composed to play with the varying shades and the play of light of the surrounding hills. (Ill. 1, 2)



Ill. 1. Golden Gate Bridge Bridge, source: www.picjumbo.com

Ill. 2. Tower of The Golden Gate Bridge against foggy sky, source: www.picjumbo.com

In 1940 there was a well known disaster of the Tacoma Bridge. The bridge located in the state of Washington in the US has the span of 853 meters. The wind blowing with the speed of up to 67 km/h moved the structure of deck into the torsional movement with the magnitude 8.5 meters; after 30 minutes the first parts of the deck were falling apart and after one hour the whole load-bearing portion of the deck collapsed.¹²

Since that time, one started paying more attention to stiffness of the decks. The result came in the form of suspension bridges with very stiff trussed construction of the decks, sometimes being very heavy. Some aerodynamic studies of bridges of high span were conducted in addi-

¹² www.budowle.pl

tion to the generic design computing. This helped design exceptionally streamlined bridge, whose shape is essential to cut the streams of air and prevent air vortex.

The Mackinac Bridge built in the fifties was the third bridge of the length of the suspension span over 1000 m. Completed in 1957, it has the main span with the length of 1158 meters. The Mackinac Bridge cuts the strait of the same name located between the lakes of Michigan and Huron. It is regarded to be the most solid suspension bridge. Given its location, it was suitable for heavy winter atmospheric conditions. Thanks to the competed design, it can withstand the pressure of wind blowing at speed of 1000 km/h.

The elements of trussed construction of the deck, carrying ropes and suspender cables as well as guardrails were painted in dark green colour which blends well with the surroundings. Non-aggressive colour of the bridge stresses the presence of the bridge. The vertical frame towers come with horizontal cross-braces. The dominant bright colour of the pillars stresses their strength features, and distinguishes these elements throughout the overall architectural design. The accentuation of the deck is stressed by the continuity of the curvature of the road present in all spans and the drawing of its lattice structure in the scale of the bridge.

In the sixties built were three bridges whose spans were over 1000 meters: Forth – 1006 meters, Verazzano – 1298 meters and Salazar – 1013 meters.¹³

The Forth Bridge was opened in September 1964 in Scotland – it was the first suspended bridge in Europe whose span was over 1 km. Steel towers are of height of 156 m and the load-bearing deck makes an impression of the bridge to be extremely light.

The next bridge – going through the Verrazano strait – was opened in November 1964. It was the longest suspension bridge until 1981. It has steel towers of the height 210 m, and the hanging span is supported by four cables.

Salazar was the first bridge over the Tag River in Lisbon (its current name – since the revolution in April 1974 – Ponte 25 de Abril – The Bridge of April 25). The construction was finished in August 1966, and its spread was the largest in Europe until 1970. The steel tower are of height of 190 meters. In the nineties the bridge was reinforced and radically rebuilt. For instance, to the two already existing main cables two new were added and the lower deck was prepared for the railway traffic. The bridge is painted in red colour and that is why it is sometimes referred to as the Lisbon's „Golden Gate”.

In the seventies, only a single bridge of impressive span was built – Bosphorus Bridge. It was opened in October 1973 in Istanbul and has the span of 1074 meters (the longest in Europe since 1981). It was the first Intercontinental bridge from Europe to Asia. The bridge is very characteristic because of oblique suspenders and streamline shape of steel box girders. Steel towers are of height of 165 meters. Only the middle span of the bridge exhibit the hanging structure (side spans have girder structure).¹⁴

The eighties were marked in the bridge industry by the three suspension bridges of tremendous spans: Humber Bridge (1410 m), Minami Bisan–Seto Bridge (1100 m) and Sultan Mahmet Bridge (1090 m).¹⁵

The Humber Bridge was opened in July 1981. Thanks to it, the span record moved from US to Europe. It exhibits a unique construction featuring rectangular frame of concrete tow-

¹³ Technical data: J. Virola, *Siedemnaście godnych uwagi najdłuższych na świecie mostów wiszących*, Inżynieria i Budownictwo, 2001, no. 1.

¹⁴ *Ibidem*, p. 11.

¹⁵ *Ibidem*, p. 12.

ers stiffening by horizontal beams dividing them into three areas. Lapidary form of pylons is somewhat in opposition to other elements of assumption such as: differential length of side spans and oblique position of suspenders. Carrying ropes clearly delineate the shape of the bridge over the sky. The visible of deck overhang over the contour of pillars enhances the readability of movement of forces from span on supports.

In April 1988 a complex connection between the islands of Honshu and Shikoku in Japan was completed. This Seto–Ohashi Bridge complex consists of the combination of several suspended and cable-stayed bridges. Its total length is 12,306 km and as such it forms the longest highway-railway bridge in the world. In this system there are three suspended bridges. All of them have steel towers and two-level steel trussed construction decks.

The second suspension bridge connecting the banks of the Bosphorus Strait in Istanbul was opened in August 1988 and was called the Sultan Mahomet Bridge. It has – similarly to the first bridge – steel box girder with streamline shape, however – in contrast to the first one – vertical suspender cables were applied here.

In the nineties seven suspension bridges were constructed having the spread of over 1000 meters: Tsing Ma (1337 m), Høga Kusten (1210 m), Akashi Kaikyo (1991 m), Great Belt (1624 m), Jangyin (1385 m) oraz Kurushima 3 and 2 (1030 and 1020 m).¹⁶

One among the long list of construction masterpieces – the suspended bridge over the Akashi Strait, is a continuation of the rapid technological progress initiated during the industrial revolution. This technological wonder in a master way addressed the transportation needs providing the users the safety irrespectively of weather conditions. This outstanding construction of the previous century comes as a fascinating example of overcoming indomitable forces of Nature and addressing the timely construction needs. The bridge connects Kobe with the Awaji Island; its overall length is 3911 meters and the main span has the length of 1990,8 meters. This is not the only sign of progress: along with the record sizes and remarkable strength, is the unusual architectural form of full appeal of the construction – the feature that the designers in the past could only dream of.

The unusual dynamics of this bridge is implied by its scale – the length of span and the height of towers. The strong balance component is a symmetric spatial layout of the structure. The line of sag of the carrying rope are master data and invariant in time and space resulting from construction requirements. This line by wavy, rhythmic movement determines the outline of a bridge silhouette and transparent „wall” of suspenders. The architectural composition is composed of two vertical towers and vertically arranged suspenders equilibrated by horizontal line of deck contour. The elevation of the desk is aimed at avoiding an illusion of its concavity, implied by association with concave line of carrying rope. In towers the main forces are axial compression, hence the pillars come with simple and sharp edges. Thanks to the form of their cross-bracing stiffeners the spatial character of the tower was achieved. Whereas, openwork trussed construction of the deck plays compositionally with the shape of pillars. The bright colour of the bridge emphasizes huge forces transformed by load-bearing elements, shown in the diversified landscape. (Ill. 3)

The combination of solid forms appearing from the land in the form of beam bridges with the central suspended structure forms the essence of the spatial composition of the architectural assumption of the bridge over the Great Belt Strait.

The complete length of the Eastern Bridge is 2694 meters, where the main span has 1624 meters. Side spans are symmetric and each of them has the span of 535 meters. Its construction

¹⁶ *Ibidem.*



Ill. 3. Akashi Kaikyo Bridge, source: www.vistapointe.net
Ill. 4. Great Belt Est Bridge, source: photo by the author

started at the end of 1991 after three years of research and development. The completion of the project was realized in 1998. Under almost each condition, the task realized by the designers was enormous. In addition to the suspended bridge, the project anticipated 23 flyover spans – 14 at the east i 9 at the west side of the suspended bridge.

The vertical concrete towers of height 254 m over the sea come as a simple frame shape of sharp outline. Each pylon was split into two equal parts using a single horizontal brace beam narrowed in the middle part. The visible line of main cables accentuates the unity of the suspended structure. The equilibrium of the composition of the bridge is emphasized by the symmetry of assumption, parallel nature of suspender lines and their uniform spacing and rhythm of access spans supports. The nature of the form of structural elements of the bridge is consistent with the values of forces conveyed by them. Furthermore paths of force lines are present in each of these elements. The elevation of the track in all spans creates an impression of continuity of the bridge, which appears here with an enormous intensity. The spatial form of the anchor blocks in the form of triangular trestles, do not reflect the magnitude of load which are conveyed by them, was adopted in terms of shape to the configuration of lines mapping the direction of forces.

In the construction of the Great Belt bridge the combined effort of architects and engineers has resulted in a unique piece which created one of the most elegant bridges in the world – clear and deceptively lightweight, which is the real proof of the truth of the principles governing the suspension bridges. (Ill. 4)

In the nineties two bridges of record length were constructed. In the Chinese province of Jiangsu, in September 1998 was open a big bridge Jianguyin over the Yangtze River. The main span of length 1385 meters locates it in the first ten record bridges in terms of the length of the span of longest suspended bridges. The Kurushima–Kaikyo Bridge in Japan located over the Inland Sea of the Shikoku Island, was completed on May 1, 1999. It consists of the three bridges suspended on ropes anchored deep within large blocks at the ends of crossing. The overall length of crossing is 4015 meters and is somewhat longer than Akashi – Kaikyo being in this way the longest suspended constructions in the world.

Unquestionably, in the perspective of the past it can be concluded that the objects built in the second half of the nineteen and the twentieth centuries, namely suspension bridges, created the basis of the contemporary art of construction.

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