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The first wire suspension bridge : Geneva 1823

Le premier pont en fil de fer : Genève 1823

Die erste Drahtseilbrücke : Genf 1823

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SUMMARY
The first permanent wire cable suspension bridge built in Geneva in 1823 was the work of Guillaume-Henri Dufour, a man famous in his own country as one of the founding-fathers of modern Switzerland, diplomat, general and cartographer, but not as a civil engineer. Dufour was very concerned with the quality of his structures; not one of them failed in a period caracterized by many suspension bridge collapses. Dufour was also very concerned about the aesthetics of his structures, and his drive to perfection in both detailing and appearance gave rise to an intense development, the first step of which is described here.

RESUME
Le premier pont permanent en fil de fer, construit à Genève en 1823, fut l'oeuvre de Guillaume-Henri Dufour. Dans son pays il est connu comme un des fondateurs de la Suisse moderne, comme diplomate, général et cartographe, mais il reste pratiquement inconnu comme ingénieur civil. Dufour s'occupait beaucoup de la qualité de ses ouvrages d'art: aucun ne s'effondrait dans une période caractérisée par la chute d'un grand nombre de ponts suspendus. Dufour s'occupait également de l'esthétique de ses ponts, et sa tendance à la perfection dans les détails et l'apparence initia un développement dont le premier pas est décrit ici.

ZUSAMMENFASSUNG
Die erste permanente Drahtseilbrücke, 1823 in Genf gebaut, war das Werk von Guillaume-Henri Dufour. In seinem eigenen Land ist er als einer der Gründer der modernen Schweiz bekannt, als Diplomat, General und Kartograf, aber nicht als Bauingenieur. Dufour beschäftigte sich stark mit der Qualität seiner Bauwerke. In einer Periode, die durch den Einsturz zahlreicher Hängebrücken gekennzeichnet war, stürzte kein einziges seiner Bauwerke ein. Dufour beschäftigte sich ebenfalls mit der Aesthetik seiner Bauwerke. Seine Neigung zur Perfektion sowohl in seiner Detailierung als auch im Aussehen seiner Bauten leitete eine intensive Entwicklung ein, deren erster Schritt hier beschrieben wird.

Chain suspension bridges had been known in China and the Himalayas for about 2000 years before a revolution in their construction began when James Finley erected the first to have a suspended deck, permitting vehicular traffic, in 1796. For the first time, the relationship between the deadload and the liveload of a structure was reversed and bridges could be designed to carry more than they themselves weighed. The economy of the new structures over the traditional bridges of timber or stone was nothing short of miraculous to the laymen of the day, and Charles Dupin, the french technologist, counted the chain bridge among the wonders of the age together with the perfected steam engine, the hydraulic press, gas lighting and the miner's saftey lamp.(1) Then, in 1822, with the advent of the first permanent wire cable bridge in Switzerland, the basis was laid for the development of the cable suspension bridge we know today. From the "Grand Pont Suspendu" of Fribourg onward (1834), 13 bridges have succeeded one another as the world's largest span. All with the exception of two - the Firth of Forth (1890) and the Quebec (1917) cantilevers - have been wire cable bridges.

In the summer of 1822, Marc Séguin, who was to become one of the most eminent engineers of 19th century France, and his four brothers erected a trial wire cable catenary bridge of 17 m span at Annonay in Savoy. This structure had been preceeded by others, notably the 124 m catenary over the Schuylkill by Hazard and White in Philadelphia and the Galashiels wire-stayed bridge of 33 m span by Richard Lees in Scotland, both built six years before. Like them, the Annonay bridge was a temporary structure, and like them too, each builder had no knowledge of the others. Unlike them however, the Annonay test bridge became the starting point for the development of wire cable suspension bridges.

The editor of the reknowned scientific and literary journal, the Bibliothèque Universelle of Geneva, heard of the experiment and travelled to Annonay to investigate. He returned fascinated with what he had seen and determined to build such a bridge in Geneva. A letter was dispatched to Séguin inquiring as to the possibility of erecting a footbridge over the fortifications of the city. Séguin's reply, dated October 21, 1822, contains the preliminary design, calculations and cost pricing for what was to become the first permanent suspension bridge on the european continent and the first permanent wire suspension bridge in the world.

Séguin's 11-page letter throws much light on the engineering attitudes of the time and on the state of the art just a year before Navier published his first major work on statics (2), which, together with his more famous work of 1826 (3), constitutes one of the foundations of analytical statics as we know it today. Séguin was invited to Geneva to discuss the matter with Guillaume-Henri Dufour, the State Engineer. Dufour then presented his project, based on Séguin's proposal, to the bridge company which had swiftly been founded, in November 1822.

Dufour had been trained at the new Ecole Polytechnique in Paris and at the Ecole d'application at Metz. Although his command of mathematics and engineering was more profound than that of the self-taught Séguin, there was very little to add to what had already been stated. Before beginning such a novel structure, Dufour made a series of experiments to determine the tensile strength of wire. We can no longer imagine the difficulties which then accompanied such an undertaking. Karl von Sickingen had published some data in 1782, and Séguin himself was running some tests at the time, but there was no reliable information on the properties of drawn wire.

Mathematics had by that time begun to influence engineering practises, especially in France. The Ecole des Ponts et Chaussées had been founded in 1747 under the directorship of Rudolphe Peronnet, and the Ecole Polytechnique, which received its final form in 1802, was strongly influenced by Gaspard Monge, the inventor of Descriptive Geometry. Material technology was far less advanced, and the lack of available data was compounded by the fact that weights and measures often varied from city to city. Tests had no common basis for comparison: Barlow reported in 1818 (4) that Telford's experimental results on iron included the friction of the test apparatus whereas the friction in Samuel Brown's apparatus reduced the force measured.

Little wonder then that Dufour began his own experiments. He set up his workshop in the building of the "machine hydraulique" in Geneva and already had a paper ready for a scientific meeting on February 20. The strength of the wire he measured varied considerably for wire from different sources. The thinnest wire resisted twice the breaking strength of bar iron or about 80 kg/mm^2. Both Séguin's and Dufour's experiments varied less than ± 2·5%, a far better result than the 12·5% reported by Navier for Marc Isambard Brunel's experiments in London. Wire of up to 5 mm diameter withstood average strains of 60 kg/mm^2, bar iron up to 6 mm : 40-45 kg/mm^2 and bar iron over 6 mm : 25-30 kg/mm^2.

In the course of his experiments, Dufour learned to differentiate between an apparent increment due to straightening of the wire and a genuine stretching under strain. This fact was of prime importance for the success of Dufour's cables in comparison with those of Séguin and others in France. Séguin who had concentrated on other aspects of wire testing, missed this point entirely. As he had observed small increments in loading to give small increments in length, he concluded that small differences in wire length in the cables would mean small differences in tension! (5)

The swiss and french immediately adopted wire for suspension bridge construction whereas the british retained the eye-bar chain. The reason was economic: iron was relatively cheap in Britain, whereas in Switzerland and France it was very expensive. On the other hand, industrial labour was cheaper on the continent than in Britain. Telford therefore found a wire cable version of his Runcorn Bridge project to be twice as expensive as a chain version, (6) while Dufour and Séguin were justified in going to any lengths to save iron.

Dufour pretensioned all his wires in a rack before binding them together. He found that his cables has an unfortunate tendency to spiral which inspired him to develop another method for his later bridges. Séguin's cables, on the other hand, were made of wires slung by hand into parallel catenaries and then bound. According to Joseph Chaley in his report on the building of the Fribourg bridge in 1835, Louis-Jean Vicat, an eminent material technologist and early suspension bridge builder himself, suggested Dufour's method as a solution to the problem, without however crediting him for it. (7)

The next step was to test a model, and Dufour built a 12·6 m long test structure in a factory hall. He used it to test the attachment of the suspenders and also for examining methods for stiffening the deck. Dufour examined each problem independantly and made no attempt to treat the problem systematically as a whole. He designed many solutions to specific loading conditions, such as stiffening the deck flooring, rigidly fixing the joists into the abutments and stays under the deck, but it was Séguin who was to develop the first stiffening truss the following year. In the course of his tests, Dufour noted the fact that the stability of the bridge increased with increasing loading, a fact which Navier related to increasing span later that year. The erection of the bridge then proceeded rapidly, and the Pont Saint-Antoine opened to the public on August 1, 1823.

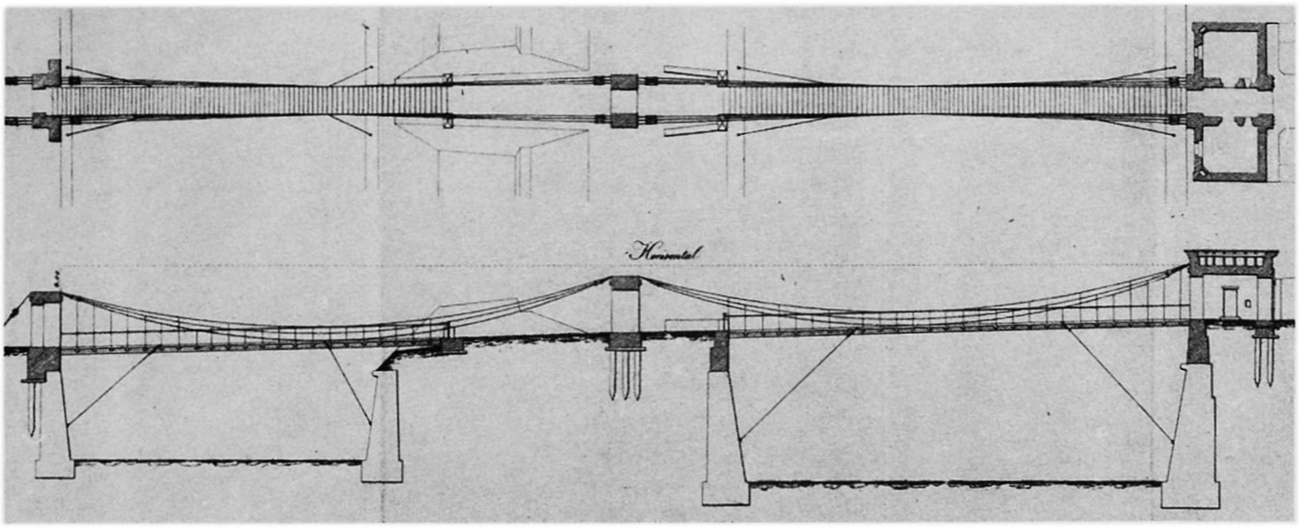

Fig.1 Guillaume-Henri Dufour: Pont Saint-Antoine, Geneva 1823. Plan and elevation
A double span of twice 42 m with 6 cables of 90 2·1 mm wires each supported two decks assymmetrically arranged. The cable size was limited for reasons of weight, as they were prefabricated and hoisted into position individually. Each cable was manufactured in five lengths: two 36 m sections spanned the gaps, and 3 short ones lay over the piers in order to facilitate replacement should this prove necessary. Several coats of varnish protected the finished cables which were anchored by means of iron bars attached to the cable ends some 2 m above ground level.

The coupling for the main cable sections seems to have been developed from Telford's eye-bar link. The Cable ends were bent into loops and spools passed through them. The opposing spools were then linked by means of two short wire "belts" one on either side of the centered cable. The odd transfer of a two-dimensional structural detail to the three-dimensional, non-directional problem is inexplicable. Dufour was well-trained in the three-dimensional visualization of structural problems, and the reason for this dangerous solution remains a mystery. However Dufour never again used it in any of his subsequent bridges.

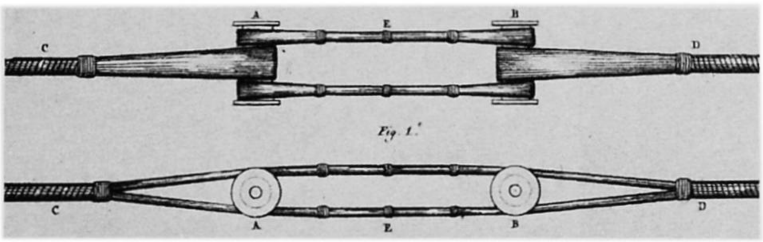

Fig.2 Coupling details for the main cables
The cables lay 20 cms apart horizontally over the piers, but at mid-span they were pulled in toward the deck and lay vertically above one another. Originally this was for stability, but Dufour later argued that it was to transmit the load to the middle of the piers. This meant that the cables had to be of different lengths. The "garland" system was a most awkward arrangement and Dufour abandoned it thereafter, gradually developing the twin cable in several well-documented stages. French constructors however, retained the "garland" system for many years.

The mean ratio of sag to span lay, as Séguin had recommended, between 1:10 and 1:12, and followed neither the british (1:20) nor the american (1:7) preference. It was essentially chosen for economic reasons, balancing the disadvantages of increased cable tension in the flatter cable against flexibility in the steeper. The cables expanded differently for temperature changes due to their different lengths. Therefore each suspender hung alternately from only one of the cables. As they were 130 cms apart, each cable was only loaded at 390 cm intervals. Dufour found the resulting "graceless polygons" as he termed them, esthetically disturbing. (8) This provided him with the incentive to develop the parallel cable arrangement. Dufour's design decisions were often influenced by his sense of esthetics, a fact which he readily admits in his writings.

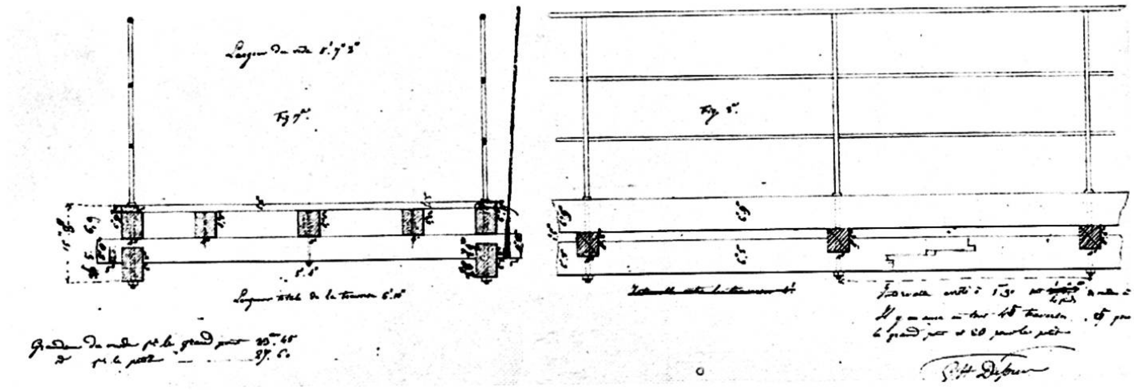

Fig.3 Sketch of deck construction in Dufour's hand

The suspenders were of wire simply looped over the main cables and secured by a binding of wire, and the crossbeams hung in stirrups from the suspenders. It was these stirrups which Dufour chose to test in his capacity of State Engineer upon the lapse of the 20-year bridge charter and its reversion to the city of Geneva in 1843. The stirrups had always worried him as the wires passed under the crossbeams and could not properly be checked. But he found them to be in excellent condition and could discover no fault in the structure. The pioneer Pont Saint-Antoine stood for about 40 years and was only demolished with the removal of the city fortifications between 1860 and 1870.

The development of Dufour's detailing from project to project, his reactions to french developments and the french reactions to his, are all fascinating to follow. Taken together, they clearly document the development of the wire cable suspension bridge which was to capture the world record span in 1834 in Fribourg and to keep it but for a brief period ever since.

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