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The suspension bridge by iron chains on the Garigliano Real Ferdinando. An example of innovative construction technique in Naples and Italy in the Bourbon Age in 1832

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«The suspension bridges by iron chains always rise doubts on their solidity. Even without knowing the laws of the mechanics, it will be easy to realize how difficult it is to try such a venture». By this assertion, reported on a nineteenth-century publication, it is clear how the spread of these daring constructions struck the common imagery all over Europe. Therefore, we can affirm that in the history of science and technique, the construction of a bridge is one of the most interesting chapter both for the technical value of the structure and for its cultural implications. The bridge, considered one among the main constructions of the engineering, has stirred up, since the beginning of the civilization, the creativity and the technical ability of homo sapiens who probably saw in it the first incentive towards the progress, as Kubrick could have pointed out in his memorable film «2001: A Space Odyssey». The famous scene in which the bone turns into a space shuttle symbolizes the developing arch of human achievements; through this representation, as engineers, we have to consider that structure as a creation which syntheses in itself not only the high specialized nature of the technique but even the extraordinary expression of the constructive excellence which it arouses.

As a matter of fact, the suspension bridges represented the expression of a culture which, between the eighteenth and the beginning of the nineteenth century, thanks to the economic growth of the Industrial Revolution in England, saw the development of the technical thought which spread over many social fields and unburdened the twentieth century of the load of the Romanticism.

The scientific thought developed free and progressive, while Europe was involved in the struggle between liberals and supporters of the absolutist monarchies which were always been hostile to the sciences and to the economic development. This revolution, conceived as the pursuit of both a new political establishment and thought, led to the creation of the new middle twentieth century Europe; it had as consequence the end of that contrast between rationality and history which French Revolution was based on.

The consequence, quoting Benedetto Croce's words, was that «. . . the breaking of the bonds, which had hindered and kept on hindering industry and trade development, was an effect of the need to vent the creativity, the individual value and the competition, and of the need to increase the wealth which, generated by everybody or everybody belonging, was however the wealth of whole society and just for this reason it was useful».

The researches in the constructive and static techniques of suspension bridges developed in an age characterized by monumental engineering works in several fields and by the use of the iron, which gave market opportunities to the industry. Besides such advanced studies were closely connected to the scientific thought, developed by researchers in the field of civil engineering on the static laws and its related applications. Furthermore the necessity of the bridge constructions involved an alteration of the scenery, increased by the usage of a non-natural material like the iron which took the place of the wood; it is important, however, to point out that a suspension bridge was a more suitable supplementary part of the scenery compared with the masonry bridges built since the ancient times. Nevertheless the necessity of developing the construction of the bridges complied with the man's will who wanted to achieve something concrete, which not only changed the scenery but even had a remarkable utility; in fact the idea of *scenery* is closely connected to the idea of *place*, conceived not only as a location of buildings but especially as a complex «. . . including concrete things with their material substance, shape, suitable placing and colour». Considering the engineering and the architecture to be at man's disposal for making easier his living conditions; it is clear that this new man, born of the French Revolution, naturally aimed at realizing such constructions. The importance of bridge implementations, in nineteenth century, did not merely rise from trade and military necessities, but even from the wish to satisfy the cultural thirst, born after the darkness of the reason. It was necessary, to exploit the places at their best, to come to a compromise with the *genius loci*, conceived «as the whole of the difficulties which man has to face to achieve the opportunity of dwelling»: as regards the bridges, the difficulties correspond to the geomorphic peculiarities of the land.

This introduction aims at explaining how, in that period, the cultural impulse gave rise both to researches and constructions all over Europe; examples of this cultural impulse were the several suspension bridges, planned and built particularly in England and in Russia by skilful engineers supported by sovereigns, inclined to such innovations as conscious of their benefits for the territory distribution and for the economy. Besides the bridge constructions were supported by France which, after Napoleonic conquests, had the necessity of organizing militarily the wide territory of the Empire; therefore the bridges represented the natural shortening of the distances for the transport of the troops. As a consequence of these necessities, engineers specialized in the implementation of such structures were born, inspired by Rondelet's treatises both for cultural and constructive aspects. In order to understand the cultural conditions and the technical knowledges in which the planning of the suspension bridges developed, we will describe some of them.

Among the first constructions, the English bridges are noteworthy: the Bridge on the Straits of Menai, planned in 1818 and opened to the public in January 1826, and the Conway Bridge, linking England to Ireland and built between 1822 and 1826, were both realized by Telford, and the Bridge of Hammersmith was built by Clark and Brown between 1825 and 1827. Besides it is important to mention the three suspension bridges constructed in Russia in Saint Petersburg, named *Egyptian, of the Four Lions* and *of the Four Gryphons*, built by Traitteur between 1825 and 1826.

The planning genesis of the bridge on the Straits of Menai was very complicated. The first plan, dated to 1801 by the engineer Ronnie, could not be realized because of the exorbitant price estimated at 259.140 pounds. After considering several solutions, all of them impracticable for different technical reasons, in 1810, after Ronnie's death, the project was commissioned to the engineer Telford. After discarding a first plan with big arches, he projected a single span suspension bridge made up of iron and cast iron with a 500 feet span and a 100 feet maximum height above sea level. This project was substituted with another one, characterized by two iron-cast pyramidal piers, supporting a 560 feet span. The chains had to be realized with six cables, each of them composed of 36 square section bars; a metallic bar, spirally wounded round the nucleus, contained each chain, characterized by a four inches diameter. All the chains were anchored in the masonry piers, placed to the ends of the shores.

Telford's projects were supported by load and deformation tests, carried out on iron bars by Barlow, a mathematics teacher, who estimated at 29 tons the strength value of the constructive system of the catenaries. Telford improved the experimentation, achieving a good knowledge of the behaviour even thanks to the structural calculus method formulated by Provis, his teacher, and determining a chain section of 1 square inch to which a 11 tons testing load is applied. The experimentation was carried out by a machine, invented by Provis, based on the calculus of the friction generated by the stretch of the bar under tension; the bar was hit with strokes of hammer which produced vibrations useful to calculate the bar strength even under non-axial stress.

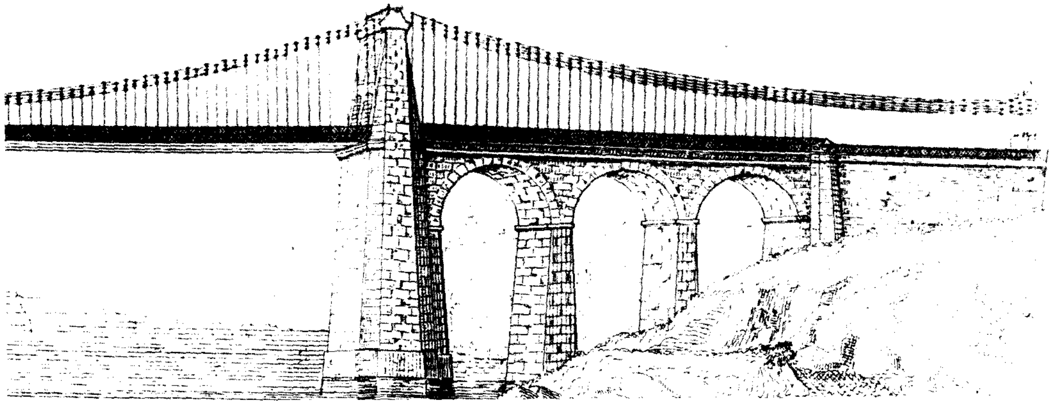

Figure 1
The Bridge on the Straits of Menai

The result was considered positive according to the elongation shown by the bar (fig. 1).

After the tests preparatory to the executive planning, the chosen solution was characterized by four and three stony arches which, placed on the shores, delimited two frustums of pyramid. In each of the two frustums of pyramid, four cast-iron plates were placed, each of them should clamp twenty chains in a vice, for a total of 80 chains, for the construction of the bridge characterized by a 28 feet wide deck, divided into two roads separated by a pedestrian crossing.

As concerns the executive planning, Telford found a successful solution to divide the loads equally on the pyramidal sections, in order to allow the minimum sliding of the chains to avoid any expansion. The problems related to the thermal expansion and to the swings generated by wind effect were solved inserting into the stony section cast-iron cushions, on which cylinders, permitting the sliding, were laid. Telford paid his attention even to the bridge corrosion, protecting the iron structures with the so-called «oil plaster». The metallic components were dipped into linen oil soon after its heating in a kiln at a very high temperature. After the bath, the metallic components were put again into the kiln, at a lower temperature for a period lasting three or four hours, in order to have a deep diffusion of the linen oil into the pores of the metal. This procedure finished by rubbing those metallic parts with oil-soaked flannel clothes.

The construction of the Conway Bridge started in April 1822 and ended in 1826; it was projected by Telford and accomplished by Provis. In order to place the structure, which had to link the English shore to the Irish one, in harmony with the scenery dominated by the ruins of an old castle, Telford projected, for each end of the bridge, two battlemented towers including the cast-iron plates which clamped eight catenaries in a vice, each of them composed of five metallic cables. On the catenaries a metal structural work, on which a double wood layer created a passage, was placed. The better conditions of the wind and of the streams made possible a simpler structure of the Conway Bridge which, compared with the one on the Straits of Menai, presents a superior span.

The Bridge of Hammersmith was built between 1825 and 1827 by the engineer Clark and by Brown, an army captain. The two masonry piers, erected on the two shores and based on wood piles, contain the anchorages for the eight catenaries which represent the core of the structure. The sliding of the chains on the cylindrical rollers was used also for this bridge, as it is possible to understand from the plan reported in the figure. A wood-floor, proofed by using tar and pitch, ensured the practicability of the carriageways (fig. 2,3).

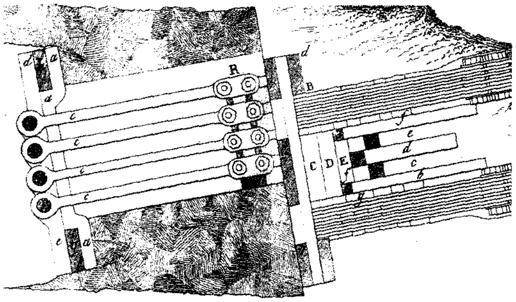

Figure 2
The Bridge on the Straits of Menai. A particular

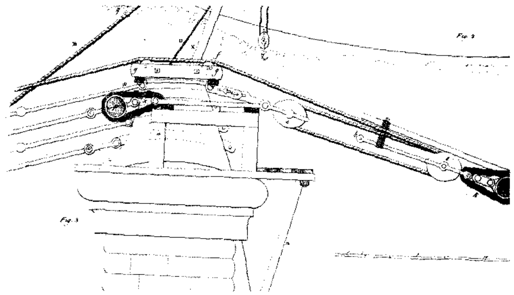

Figure 3
The Bridge on the Straits of Menai. Sliding of the catenaries on the piers

The construction of the Egyptian bridge in Saint Petersburg started in 1825 and ended one year later. It is characterized by a structure made up of catenaries, clasped to six Egyptian cast-iron columns and connected by a cast-iron beam containing the sliding rollers of the catenaries. All the columns and the cast-iron elements were decorated according to the style of the ancient Egypt, famous in that time both for the archaeological discoveries and for the Napoleonic military campaign. In order to antiquate the bridge, all the metallic parts were tinged with «bronze antique» colour. All the catenaries, housed in two cast-iron cables, extended to two granitic masonry blocks; the gap between the chain and the covering cable was filled with a mixture of wax and tar as a protection against humidity and corrosion. The carriageways of the bridge were made up of a wood double layer deck; the first layer was proofed by using pitch and tar. The bridge *of the Four Lions* and *of the Gryphons* are similar to the Egyptian one (fig.4).

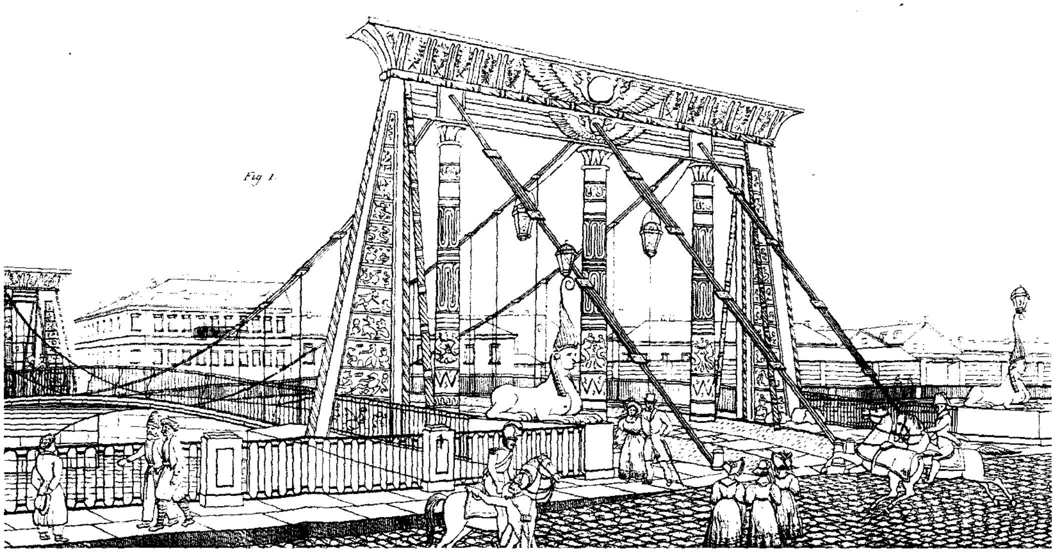

Figure 4
The Egyptian Bridge

All the above mentioned bridges, together with other examples of suspension structures, were built in Europe at the moment in which the construction of the suspension bridge on the Garigliano, near Neaples, was conceived. Since the old age, there was the necessity of a link between the two banks of this river, to make the connection between Naples and Rome easier. The first Bourbon sovereign who took into the right account the idea of constructing a bridge on the Garigliano was Ferdinand IV who, in 1788, commissioned his experts to carry out a research. The construction of a single span stony bridge was proposed to the king, but this project was never put into practise because of its excessive cost. Furthermore, the bad river floor conditions precluded the stability of the span abutments, which should have been liable to differential failures; even for this reason, in 1823 the construction of a suspension bridge was proposed to the king. This choice perfectly took place in the industrial set-up of the Reign of the two Sicilies: as a matter of fact, the iron production was an incentive for these people, who saw in the construction of the suspension bridge an opportunity, for the Reign, to attain the primacy for this kind of construction in Italy. The opportunity became true thanks to a young engineer, particularly skilful in planning, who, in December 1825, presented the king a research on the bridge and got from him the authorization.

Luigi Giura was born at Maschito, in Basilicata, on October 1st, 1795. He graduated in 1815 at the «School of Bridges and Roads», founded during the Napoleonic decennium, from which the prestigious school of Neapolitan civil engineering arose. According to his interest in the new techniques connected to the use of iron rising all over Europe, in 1826 he set out on a study journey to England and Germany, which gave him the opportunity to achieve the technical knowledges to start the construction of the bridge *Real Ferdinando*. According to the planning laws of that period, the executive planning had to comply with the following building rules:

- One or many chains are placed in the vertical planes of the bridgeheads; they form, in the upper area of the riverbed, that curve named catenary; they lay on a point on each of the two pillars erected at a given height on the banks; then they are driven into big stony blocks deeply laid underground.
- From the upside down arches of the chains, in such a way displaced, fall some vertical bars named hangers, which support the floor.
- Each chain is composed of three branches. The floor is supported by the branch placed between the two pillars and named of suspension. The other two branches, which start from the tops of the pillars and end in blocks, must hold the branch of suspension, and for this reason are called of restraint.
- The point in which the branch of suspension connects to the branch of restraint, that is to say the point where the chain touches the top of the pillars, is named point of suspension.
- The points of restraint are those where the restraint lines and their ends are driven into the walls.

Therefore the structure was organized so that the loads should rest on the suspension lines with tension, the maximum value of which, realised in the suspension points. The stresses were transferred from there to the branches of restraint so that they could be held by the masonry pillars in which the anchor plates were housed.

Luigi Giura paid particular attention to the suspension points, improving the techniques used by Brunel in London, to fit them on the bridge *Real Ferdinando*, marked out by two chains in a vertical plane. This particular point was realised through a pendulum made up of three big vertical links which allowed each branch of suspension and each branch of restraint to swing; this was made easier by a second pendulum, properly unrelated to the first, around the hinge of which the two above mentioned branches joined up.

Another important aspect studied by Luigi Giura is the hooking of the chains to the terminal plates of the catenary; besides the care for the constructive details, Luigi Giura worked so that the resultant of the tensions was always vertical. This was possible setting the pendulums in a perfectly vertical position and calculating the variations of load and temperature, which should be little determinative for the point of appliance of the resultant itself. The pendulums, placed inside the masonry piers, could easily swing because of their greater length compared with the hooking pins and this allowed to get a very low friction value. Therefore, the whole static system gave the opportunity of getting a very low concentration of tensions at the piers level.

Two Egyptian style columns, surmounted by capitals ornamented with palmettes, placed on bases covered with freestone, were built on each of the banks. The columns bore four catenaries, each of them made up of two rectangular section bars, so that they formed the suspension line, in the shape of an upside down arch, and lines of restraint which, starting from the top of each column with an inclination of 28 grades, were clasped to stony blocks placed in underground passages, the entry of which was characterised by stony sculptures reproducing the sphinx. To the suspension catenary were connected 108 metallic bars, on which unloaded a slab made up of metallic rectangular section bars, used as a support for the wood-floor in oak crosspieces so as to build up three practicable ways, two of which were external walkways. The limestone used to shape the capitals of the piers had a 600kg/cmq pressure resistance, therefore it was quite resistant, like all the elements used to construct the bridge, to the effective acting loads.

The construction of the bridge ended in 1832 and was inaugurated by the King Ferdinando II himself; its cost was lower than the one estimated. The *Real Ferdinando* preserved a good state till the Second World War, when the Germans, retreating from Naples, set the central span off. By Giura's executive plans, kept at the Public Record Office, it was possible to estimate the total weight of the bridge at 260 kg/mq; the bridge structure was estimated to bear an 240kg/mq overloading with a chain stress of 500 tons (15 kg/mmq). It is necessary to add that, as concerns the static planning, the bridge had some defects, caused by the considerable deformation it was submitted to and for the lack of braces that compromised its resistance to wind and seism.

All the metallic structural work used for the bridge construction came from the industries of the Neapolitan Reign as token of an entrepreneurial and trade ability, never too much appreciated. The 70.000 kg of iron, used for the bridge construction, were made by the iron-foundries of the Prince of Satriano.

In the original Giura's drawings, the bridge was described with a wealth of detail. The voluminous fascicle, containing the plans signed by Giura and kept at the Public Record Office, is the token of technical choices, due to his own abilities and his being continuously abreast of the science; his technical choices were supported by laboratory tests which gave the opportunity to proportion both the chains and the hookings.

Nowadays the bridge has been restored with advanced techniques aiming at recovering the functional and performance levels of the end parts, still preserving a good state, and aiming at rebuilding the central part made up of aluminium. Therefore *the Real Ferdinando* keeps on holding the Italian technological primacy: it was the first suspension bridge in the past, it is the first aluminium bridge in the present.

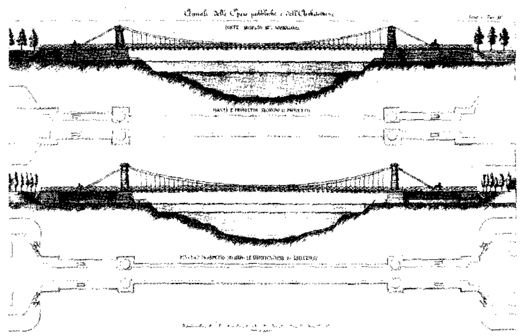

Figure 5
The bridge on the Garigliano, in Giura's drawings

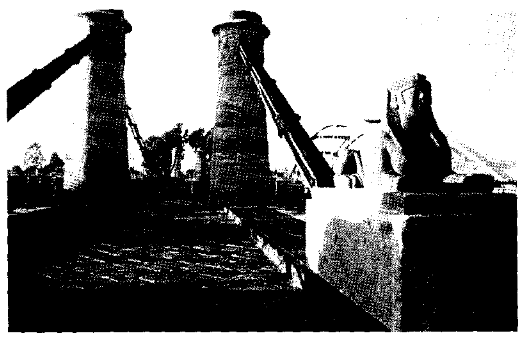

Figure 6
The bridge on Garigliano. A view with the sphinx