Concept and construction methods of arch bridges in Italy

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ABSTRACT: The Italian arch bridges history find its roots far off time: Italy has in fact a long infrastructural tradition that derives from the Roman period and owns a lot of example of the Italian importance in all the world.

The architectural arch shape found in recent years a new life: the new construction bring back to the modernity the traditional learning with different materials and techniques and with the desire to create span with length more and more long. Today Italy can't show off recent very long arch bridges, as in other countries, but there are many important new structures with an attractive aesthetics and innovative conceptual design and construction methods.

In the following paper the evolution of arch bridge type in Italy is analyzed and discussed, and finally some recent projects are presented.

1 INTRODUCTION

The connection between structure and shape represents the strictly relationship between engineering and architecture and in the bridge construction the shape becomes itself the structure and it is through this close comparison between the two fields that a work can be define with a good quality, when this combination allows to create works that show a formal and compositional value, but at the same time presenting a careful technological and scientific analysis. The engineering history has seen the progress of structural and construction techniques beginning since last century with geometric schemes till the construction of basic forms of architecture.

The form of the arch is aesthetically pleasant and easily integrates with the surrounding environment and its shape represents the maximum formal expressiveness of the architecture.

After a long absence period, the arch structure, which has characterized the entire history of Italian architecture from the Roman achievements, has regained an important role in the design, especially in bridge realizations and in the large covered spaces construction. This decline was due mainly to the costs of the provisional centerings necessary to sustain the arch during the erection phase.

After a long period of brick bridges and afterwards achievements in iron, steel and reinforced concrete used in many actual structural approaches and constructive forms, the new interest on arch shape seemed to almost disappear in recent years. For small and medium span bridges, for example, were commonly used in the new realizations the simple beam structures.

The return of the arch shape in the projects of the twentieth century was due to a formal as well as structural desire, inasmuch the arch architecture corresponds to its structure: arch structure resists thanks to its form, but it is certainly with the construction techniques progress and with the use of new materials, which there was the birth and spread of this particular structure. A wise use of precast elements, new high strength materials and proper studies of an efficient and highly repeatable erection stage can make the arch solution competitive again, both in terms of costs and aesthetics.

2 THE ARCH AND THE CONSTRUCTION PROBLEMS: LONG AND SMALL SPANS, THE WORLD AND ITALY

The realization of arch bridge has been dramatically reduced in the last decades in favour of other constructive types. The reason for such tendency is prevalently economical and technological, due to the fact that during the erection process the arch needs a provisional formwork to be sustained, which increases consistently the building expenses and the need for handwork. This is particularly true for small and medium spans, where the beam solution (whether continuous or simply supported) represent a simple and economic alternative. However, considering that small and medium spans represent the vast majority of the bridges dislocated on the Italian territory, it is mandatory for a good designer to research a structural solution which is at the same time economical and well inserted in the environment. In order to be competitive again, the arch solution needs to be reconsidered during its building process reducing the onerous continuous formwork with the help of precast elements and new high strength materials.

The construction problem of an arch bridge is that it presents different static scheme that between construction phases and final use. The research for innovative techniques and the careful study of the structural behavior during the erecting stages permitted to the arch solution to be competitive again, after some decades of small use, mainly due to economic reasons.

These considerations are worth not only for big spans, where the peculiar characteristics of the bridge require in any particular case study and the uniqueness of the works has always encouraged the research of constructive ways to suit the original characteristics of the individual property and the special conditions of the site which was to be built, but also for less important works, like normal and small spans, where a reproducibility in series of the bridge is necessary. This bridge typology is usually set in rural areas, crossing small rivers, and the arch solution is particularly adequate to permit a direct dialogue with structures in the place.

Therefore, a careful research of innovative construction techniques and a depth study of the behavior in the transitional phases of assembly allow to bring back the arch bridge solution into competitive for the construction of small and medium spans. The arch architectural elegance, with a change of static schemes so extraordinarily between the construction and the service phases, allows to get in symbiotic harmony with the surrounding environment through its architectural features, emphasizing the poetic of the arch shape in engineering technology lecture key.

The following graphs show the arch bridges evolution: respectively, the first what is became in all the world and the second represents the Italian situation. For both graphs have been split the examples for material, steel and concrete.

The follow graph shows how arch bridges have evolved in Italy: in addition to observing that the higher spans overcome hardly 200 meters in length, it can be guess as some important facts and historical periods have influenced the development and how there are time intervals in which we have no examples of new construction.

The use of different materials is a clear and explicit example of the differences between the country in all the world: the use of steel in the construction of arch bridges is of recent Italian realizations, however it was very usefully in many other places in the world.

With regard to the arch typology used, the research carried out in all the Italian bridge realizations found, it shows a majority quantity of arch bridges realized in concrete are deck arch bridges and that in steel there is a greater use of bowstring type.

The graph below represents the construction methods most used for the realization of the Italians arch bridges: as there can be noticed the major quantities of concrete bridges built since 1900 have been achieved with the use of a centering. This is the reason why many new Italian steel bridges have been built through intermediate supports or with the launching of the entire pre-built bridge on a bank.

Contrary to what happens in the world where the most used method is the cantilever one through the use of temporary towers and cables, in Italy almost all the arch bridges were built using the falsework.

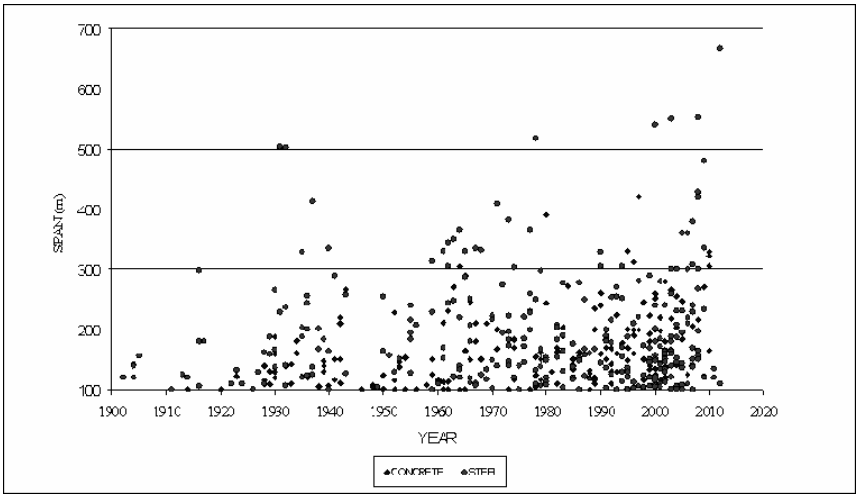


Figure 1 : Evolution of the concrete and steel arch bridge in the world since 1900 and with a span more than 100 meters in length

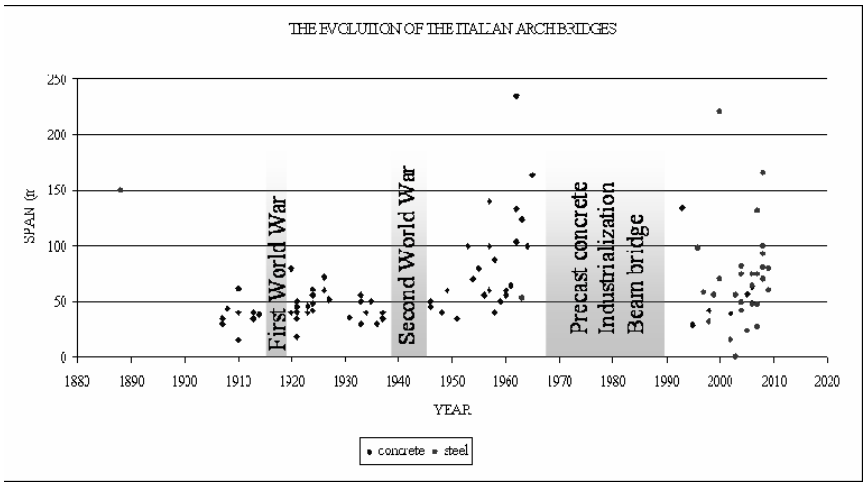


Figure 2 : Evolution of the concrete and steel arch bridge in Italy

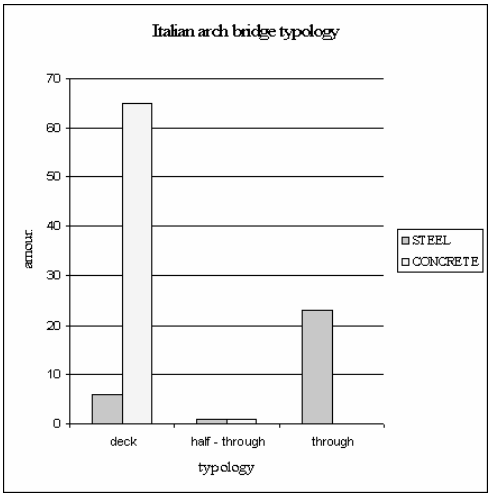


Figure 3 : Italian arch bridge typology

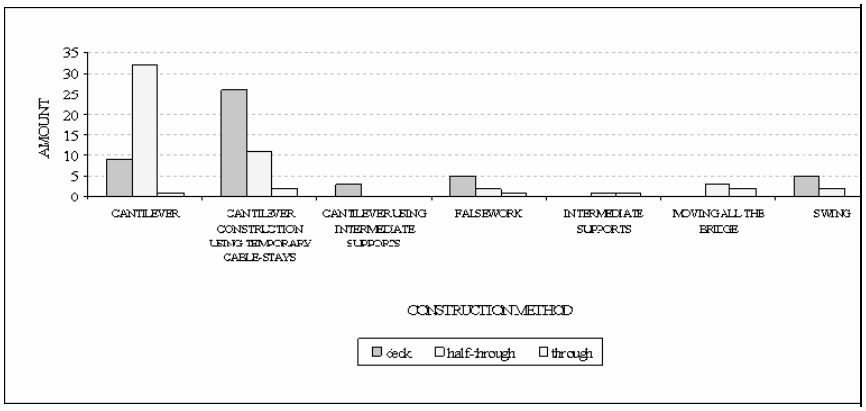


Figure 4 : Construction method used in the world since 1900 for the arch bridges with a span more than 100 meters in length

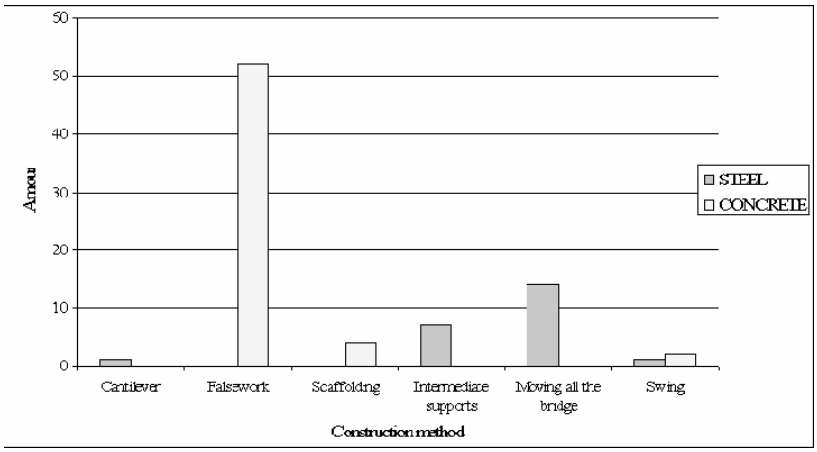


Figure 5 : Construction method used in Italy

3 ITALIAN ARCH BRIDGE EVOUTION

In the last years there is a new application of the arch typology due to the development of the construction methods and of the details. Today Italy can not show off recent very long arch bridges, as in other countries, but there are many important new structures with an attractive aesthetics and innovative conceptual design and construction methods.

In XIX century the new experience with the material and the new technologies began a fast evolution in the construction. After the First World War there was an intensive phase of study about the reinforced concrete and a lot of new structures was built with this new material. The use of steel did not find employment.

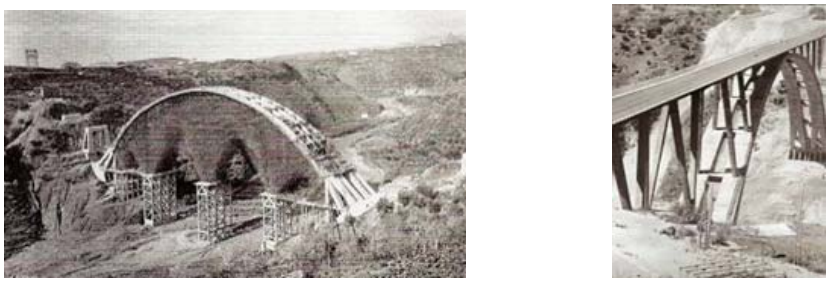
The reconstruction phase allowed to realize many important works: Eugenio Miozzi was one of the eminent engineers that used the reinforced concrete to rebuilt the bridges destroyed during the war. From 1930 he designed the most important infrastructures that characterized even today the city of Venice: the Libertà Bridge, it connects the city-island with the mainland, the Scalzi Bridge, it is in front of the railway station, and the Accademia Bridge, it was built as a temporary timber footbridge, but it can be admire and used also today.

The born of the prestressed concrete, and the consequently structural elements prefabrication, allowed to built with more economy and execution velocity. The motorway construction permitted the realizations of many new bridges built with the new material and techniques that consented to reach longer span and thinner structural section.

(a) (b) (c)

Figure 6 : (a) Libertà , (b) Scalzi, and (c) Accademia Bridges, Venice, designed by E. Miozzi, 1931-34

One protagonist of the new realizations and of the prestressed concrete use is the engineer Riccardo Morandi. It was a particular period in which the experimentation was useful to assert the new technology. The engineer was involved not only in the design phases but also in the construction process on yard. The first bridges designed by Morandi between 1945 and 1955 were all arch bridges. He used a lot the prestressed concrete technique, and he always took into account the aesthetics. An example is the Fiumarella Viaduct, built in Catanzaro for the motorway. It has a main span of 231 meters and it is still the longest Italian concrete arch bridge. The total length is 500 meters with two ribs in concrete and it was built with the centering method as shown in the picture below.



(a) (b)

Figure 7 : (a) Fiumarella Viaduct, (b) Catanzaro, designed by Riccardo Morandi, 231 m, 1962.

After the Second World War there were a rapid development of the Italian steel constructions. In this last years the engineers use steel frequently like concrete.

An clear example of a recent steel Italian work is the arch Bridge in Albenga, by Luca Romano: the steel structure consists of an arch that carries a box girder, thus forming a tied arch. The bridge spans 98 meters with a rise of 21 meters, and the deck is supported by cable. Since it was necessary to built the bridge in a short time, erection was optimized by working simultaneously in the shop and on site. Repetition of the elements and the bolted assembly permitted rapid fabrication and on site construction.

(a) (b)

Figure 8 : (a) Steel arch bridge in Albenga, designed by Luca Romano, 100 m, 1996, (b) Steel arch bridge in Pozzuoli designed by Luca Romano and Pierangelo Pistoletti, 58 m, 1997

The Arch Bridge in Pozzuoli, by Luca Romano and Pierangelo Pistoletti, is a bowstring structure, 58 meters long. The suspension of the deck is obtained through tension rods every 3 meters connected to the inclined arches. Arches are 12,5 meters high at crown. The deck has a thickness of only 80 cm to permit the free height for the underlying archaeological site.

Another steel bridge is the arch bridge over the Serchio River near Lucca, by Massimo Viviani, in 2007. The arch is a bowstring structure with a span of 132 meters. The deck is in prestressed concrete, in fact for the small and medium span this is a good solution to reduce the construction cost. The arch is composed by welded ribs.

The bridge over the Bernardino River near Verbania designed by Mario De Miranda is a Nielsen structural type realized in 2003. This structure typology gives stiffness at the arch-deck union. The typical "network" arrangement of the cables was used to minimized the structural weight and for aesthetical reason.

(a) (b)

Figure 9 : (a) Steel arch bridge over the Serchio River near Lucca, designed by Massimo Viviani 132 m, 2007, (b) Steel arch bridge over the River San Bernardino, Verbania, designed by Mario De Miranda, 2003

The bridge over the River Brenta in Piove di Sacco, by Enzo Siviero, has a good relationship with the river. It is characterized by a simple shape constituted by two inox steel arches with tubular section linked by steel elements at two thirds of the span. The system of the arches sustains a slender deck. The bridge was designed as a "door" for the close city.

Figure 8 : Bridge over the River Brenta in Piove di Sacco, Padua, designed by Enzo Siviero, 120 m, 2008

The San Donà Bridge, by Bruno Briseghella - Enzo Siviero - Tobia Zordan is an outstanding 500 meters arch structure on five bays of 100 meters each, located in a strategic area just outside the city of Venice. The interruption of the construction works was, for the case mentioned, contemporary to the introduction of a new regulation, the O.C.P.M. n° 3274, concerning seismic design and seismic classification of the National territory. This fact, since the original project was characterized by a massive box girder concrete deck on pile foundations (thus not conceived for horizontal loads at first), gave rise to the necessity of starting with an updated design aiming to achieve a much lighter composite steel and concrete box girder deck. The new deck was connected to the already built piers by means of non conventional steel-to-concrete connections ensuring hogging moment resistance at supports. The new design of the deck is characterized by a sophisticated aesthetics and by an optimized distribution of structural material obtained through an iterative design-and-check process that, starting from a FE model of the structure with a full bottom flange of the box girder would lead to a layout with the material taken away from the zones with reduced levels of stress. At the beginning of the process, a model with a continuous and full steel bottom flange was created; in the end, two wide elliptical holes were created in the lower flange of the steel box girder.

Figure 9: San Donà Bridge, Venice, designed by B. Briseghella, E. Siviero, T. Zordan, 500 meters (L = 4x100 m), 2008

4 THE PRESTRESSED REALIZATIONS

The arched bridge over the years has seen a new renaissance especially through the use of prefabricated elements that have enabled a rapid and economic construction.

The improvement of construction methods, the use of materials with high resistance that permit to reduce the size dimensions of the sections and the development of prefabrication permit today to make less burdensome the temporary works, with beneficial consequences in economic, security aspects and in the reproducibility on a large scale.

An example is represented by the bridge over the Santa Caterina Drainage Canal in Sant'Urbano, Padua designed by Enzo Siviero and built in 2002. The bridge is comprised of a single arched bay, with a span of 37 meters and on arch rise of 4,54 meters.

To construct the arch, the designers envisaged using 14+14 curved prefabricated elements in reinforced concrete, each one making up half of the arch, arranged transversally end to end, to make a single arch 7 meters wide, but shifted lengthwise in order to follow the strong slope of the arch axis with respect to the impost.

Figure 10: S. Caterina Bridge, Sant'Urbano, designed by Enzo Siviero, 39 meters, 2002

Another example of prestressed concrete arch bridge is the Mazzocco Bridge with a span of 70 meters designed by Mario Paolo Petrangeli and realized in 2007. The fifteen precast elements, necessary to compose the five ribs of the arch, were built in a prefabrication yard located very close to the bridge site. Wooden formworks placed over a concrete basement, appropriately shaped to reproduce the bottom of the arch, have been utilized. The central elements have been prestressed before launching them. Two provisional piers, 15 meters high, have been prepared to assemble the precast elements. Each pier was formed by five towers realized with small steel pipes and connected by braces.

In a first stage all the 5+5 lower elements have put in place over the foundations and the provisional piers; appropriate bearing devices have been requested to be sure that the strong inclination of the precast elements did not originate horizontal forces stressing the provisional piers. The five central elements have been placed on site in a second stage by mean of 300 ton cranes operating in the very narrow space available.

Once all the concrete ribs were in place, the prestressing bars have been inserted and jointed in the connection zone. After having completed all the connections the provisional supports have been disengaged by lowering the jack screws and the sand boxes on which the precast element were rested.

Figure 11 : Mazzocco Bridge, Pescara, designed by Mario Paolo Petrangeli, 70 meters span, 2007

CONCLUSIONS

The bridge has the main structural function of connecting two elements that are divided by an obstacle, but at the same time it is also an architectural shape. The best bridge design is when there are both attention to shape and correct use of structure.

The arch is the best solution to express conceptual simplicity, which should be a characterizing mark of a bridge. The use of the arch for the realization of big infrastructures dates back to the Romans period, as testified, for example, by the beautiful aqueducts which are present in vast part of Italy and Europe. Italy vaunts of a long tradition in the construction of arch bridges. The history of the bridges and viaducts represents the progress in the constructive techniques and the structural typology: the improvement of the construction can not be based just on formal elements, but also on the technological ones.

The last Italian realizations seek the "work completeness", holding in consideration during the design phases all the costs, the whole life cycle, with particular attention to the constructive details. The intent of the new planning is the return at the traditional shaping arched structures, using the modern constructive techniques and the new materials.

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