Achievement of small and medium reinforced concrete arch bridges

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Summary

This text illustrates the building process for some reinforced concrete arch bridges with various proportion. In these projects it has been examined not only the aspects regarding functionality but also the relationship with environment and the adaptability to different situations.

Nowadays the arch bridges are usually very expensive, they require an attentive study about the executive stages and, obviously, about the conceptual approach to the project, hence depends all the realization path. To be competitive, the arch solution has to be revisited in the light of opportunities offered by new building materials and the application of industrialized technologies, in order to reduce the economic gap and the difference in the complexity of the building process.

The object's resolution and the study of the static working for every executive stage give an industrialized building process, able to keep construction time to a minimum and to reduce expenses.

1. Introduction

The meaning of a construction is not only the resistance, a building must keep its shape and characteristics as long as possible. The resistance is an important condition but not the only purpose, nor the most important.

E. Torroja

The purpose is to revalue the use of reinforced concrete through industrialisation, prefabrication, in-place castings an relationships between metallic surfaces and concrete.

All kind of structure have their own identity but their relationship with the environment refers to the value acquired where they are placed. As a matter of fact the structural shape is connected to the executive proceeding and to the main characteristics of materials so as to be considered in a project.

Recently, there is a growing attention to the relationship between construction and territory. The interest in infrastructure formal shape such as bridges has increased, regardless of the necessary functional aspect. These infrastructural works, whatever their proportions may be, are able to enhance the value of the environment where they are located.

The choice of a building type is an important "conceptual" approach, it concerns the knowledge of materials, the static working of a structure, the economic problems, the construction time and especially the willingness to adapt our constructive method to the contextual conditions.

The arch is one of the greatest invention of classical art, it is the most proper structural element able to support and transmit loads, it gives a sensation of persistent movement.

The “free arch” is a pure structural element that represents a “jump” to climb over a distance, hence the interest in retrieving this structure form. Back in the past, it was the symbol of the honour of triumph; it requires foundations able to support the thrusts; we can get the same effect with a tiebeam, transforming it in a simple curved beam working to flexion, just as whichever right axis beam.

All this considering the particular characteristics of concrete. Its shrinkage and slow deformation caused by the dead load dispose abridgements and therefore secondary flexures, bigger than the ones we had in stone arches.

The arch solution in very expensive for the necessity of provisional supporting structure. The research must have the task to apply industrialized technologies, to valorise the use of concrete and reduce complexity and costs.

The use of prefabrication and high performance concrete allows to reduce structural elements dimension and facilitate the transport and also to reduce the needing of provisional props

2. The structural shape

The main characteristic of arch construction is the static working that involves the attendance of a horizontal thrust to the balanced shutters. The closed frame solves this problems supporting a part of the effort that arch loads on abutments.

This condition of shape is the result of different building phases, in which time has such an important role, to became a component of calculation. The structure made of prefabricated elements reach its final shape and working state, by in-place castings.

This “standard bridge” assumes the shape of a closed frame with a lowered arch connected to foundations and deck. This solution made the deck working as a chain, bringing back the thrust from the arch to the abutment till the deck, through distribution and reassemble of strengths.

It may be considered as a slow evolution of a formal order during which all the intermedial stages become part of the project’s history, such as components of its final shape and beauty.

If the ground has a limited deformability, the task of balancing the thrust of the arch can be entrusted directly to the ground-foundations system.

However if the consistency of the soil is not sufficient to guarantee that the deformations at the springers will be small, the consequent reduction in the thrust leads to an increase in the bending effects and a consequent loss of efficacy for the system because an “arched” function with mainly compressive stresses is supplanted by the bending and shear situation typical of beams.

This particular scheme is called “bowstring”, it permits to give only vertical strengths to the foundation system, but it requires a particular rigidity to avoid relative deformations between foundation block and deck.

As illustrated in the functional diagram, in balancing the thrust the solution is to associate the reaction of the ground through the foundation piles with the action of the deck, which is connected at the ends to the arch springers and thus works like a chain.

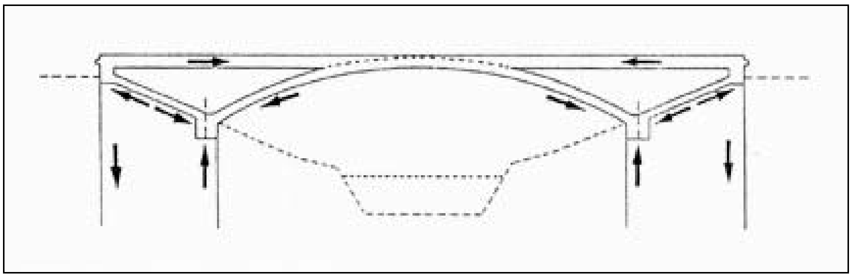


Fig.1 – Equilibrium of arch thrust

3. Executive proceeding

The traditional arch bridge construction requires provisional supporting structures and assembling operations; as regards the large sized dimensioned bridges opening, the centring is a real constructive work by itself.

The disassembling of the constructive work into a series of “basic elements” allows to build a quite complete industrialized structure and to variate the formal aspect during construction phases, without changing the structural conception of the work.

As regards the arch structure, to eliminate the needs for continuous formwork that significantly affects the global cost of the work, prefabricated high-strength reinforced concrete curved elements were placed to form arches that are installed with the aid of only one provisional prop between the spans and monolithically connected by an in-place casting.

The scheme resulting at this phase is the “three hinges arch”.

Sometimes the supporting structures are eliminated using strands that must be progressively stretched, and work as a provisional chain.

Seldom, these prefabricated elements become formworks that after the final casting are integrated into the structure, so they become parts of the supporting structure.

The deck is composed of prefabricated “predalles” slabs used as formworks and connected each other by an integrating in-place casting. The protective coverings for longitudinal pretensioned cables are necessary to support the deck’s traction, so they are conglobated in it.

4. Examples of concrete arch bridges realization process

A bridge project is not only the design of a work but also an executive proceding so exact and cured as the final result must be, so as to be evident in its shape and its structural beauty.

The following projects have the common goal to research an industrialized building process, able to keep construction time to a minimum and to reduce expenses. The main theme is the concrete arch bridge but there are some differences concerning the laying of the prefabricated elements and the structural schemes during transitional phases.

4.1. Bridge over Canale Battaglia in Battaglia Terme - Padova (1991)

Fig. 2 – Bridge over canale Battaglia in Battaglia Terme, Padova, 1991

The bridge is located in an historical and architectonic setting of great interest. It was created as alternative to the historic masonry bridge, inadequate now for the traffic load. The new structure was placed 50m after the oldest one, in direction of Padua, to maintain the view of the old one which is now a pedestrian bridge and make useful the road-intersection.

The arch structure was built through assemblage of curved beams placed on provisional props in the river bed. The arched function system was activated when the provisional supporting structure was dismantled. The foundation are made of diaphragms in a closed section of rectangular type, to achieve the maximum stiffness.

The work was planned to be built in a series of stages composed of partial executive phases that correspond to different static models.

This solution kept construction time to a minimum and it took four months to build the complete bridge.

4.2. Footbridge in Ponte S. Nicolò – Padova (1999)

Fig. 3 – Footbridge in Ponte S. Nicolò, Padova, 1999

The footbridge on the river Bacchiglione, which would service the new bicycle-pedestrian routes in Ponte S. Nicolò, crosses the river with an arch of 42m and a deck of 62m, whose extremities are linked on an inclinated slab that follows the slope of the bank, till the foundation. This structure was built without any provisional supporting structure.

The executive stages were particularly studied: the laying of prefabricated main arch structure foresees a transitory phase during which the static scheme is that of a “three hinges arch”. As the final scheme is that of arch-beam structure, it follows that the thrust due to the weight of the arch has to be balanced during the transitory phase.

For this reason strands were inserted between the springers. In a second phase the beams were placed, together with the slab casting and the solidarization of the whole system.

The foundation system consists of conical piles connected at their top with a reinforced concrete plinth that is jointed to the prefabricated arch bearing saddler.

A following phase was the in-place casting of the inclined slab along the bank till the foundation system.

In this phase horizontal steel strands were positioned sheathed into the internal foundation plinth, with the function to transmit, during the transitory stage, the arch thrust caused by the weight of the structure. During the slab casting a recess serving the draught strands was forecasted.

For the execution of the arch structure some prefabricated reinforced concrete arches with rectangular section were used. These prefabricated half-arches were jointed each other with a metallic compling provided with a driving gear to regulate the distance between two surfaces; in this particular phase a suitable counter deflection was applied to balance future structural lowerings.

To balance the weight of the arch thrust on foundations, the strands were progressively spanned, in according to the guidelines given in the building site, so as to follow the thrust values.

The deck is composed of four prefabricated reinforced concrete beams, in simple bearing on the abutments and on the haunches of the arch. When the upside slab was casted, the final scheme was determined and the reinforced concrete beams were jointed to structure extremities.

After the ageing the concrete permanent stabilizing working loads were applied on the extremities of the deck. Here strands were slowly slowed down for the temporary getting of the arch thrust, so the strands reaction can work, step by step, on the whole structure.

In this specific situation the solution kept construction time to a minimum, except for foundations; it took two weeks at all.

4.3. Bridge over river S. Caterina in Sant'Urbano – Padova (2001)

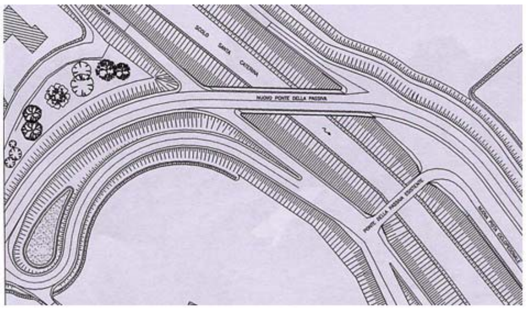



Fig. 4 – Bridge over river S. Caterina in Sant'Urbano, Padova, 2001

4.3.1. The original project

The new bridge crosses the river S. Caterina just before the existant "Passiva Bridge", which today is inadequate to the traffic load and is destined to pedestrians. Formally, it represents the evolution of precedent works, the structure is a lowered arch, the envelope is 64m and the longitudinal axes is inclinated of 36° in comparison to the river. The new bridge is placed in a natural agrarian landscape, it crosses the river and connects itself to the Provincial Road without reaching the properties that are situated on the right bank of the river.

The arch construction was forecasted through prefabricated concrete curved elements, placed side by side, the whole arch structure is 7m long.

The deck rested on prefabricated upside-down "T" concrete beams, on simple bearing on the abutments and on the extremities of the foundation blocks. An in-place final casting had to conglobate the whole structure.

The building process had to be just as the one of the previous bridge in Ponte S. Nicolò, with the same executive stages and without any provisional structure. The structure's elements had to form a "three hinges arch", whose thrust had to be supported by the foundation system; as a result the foundation's proportions could be rilevant and could have a certain influence on the whole work expenses.

By contract, the building company has proposed a constructive variant that represents a technological evolution.

4.3.2. The contractor's design

The contractor proposed the use of provisional structures, since prefabricated metallic curved formworks were placed for the casting of the whole arch. This new static scheme allowed to reduce the proportions of the foundation.

Just after the ageing of concrete the formworks for the upside slab castig were placed on the arch. The casting was made in two different moments: outstanding slab under lateral reliefs, 7m long, reinforced "Predalles" slabs to build the formwork for lateral reliefs and upper slab in-place casting complement. The whole final deck lenghts is 12m.

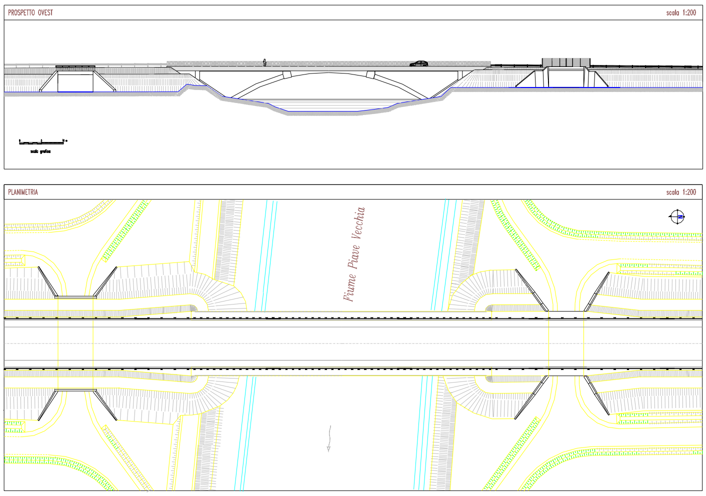
The lower structure, composed of the arch and the diagonal strut, supports the upper slab wheight during the casting. At the moment this is the static working.

After the ageing of concrete, the provisional props were dismantled. The opposite of the supporting system actions were applied to rhe completed structure.

The arch's springers were implanted on foundations made of diaphragms whose thickness is 0,80m and lenght is 20m, they built a very stiff closed structure. On the lower surface was reproduced the original geometric shape.

Fig. 5 - Bridge over river S. Caterina in Sant'Urbano, Padova, 2001

4.4. Bridge over Piave Vecchia – Venezia (2001)



This project is one of the variants for the 14 State Road in San Donà di Piave (Venice), to solve problems relating to the high traffic load in the town roads.

This is a mixed structure, 63m long with a spray arch of 45m.The construction process is similar to the previous project made in Sant'Urbano, also in this situation provisional supporting structure were mounted to support the formworks.

Prefabricated metallic curved formworks (REP system) were placed for the casting of the whole arch, conglobating the metallic structure and the concrete so as to make a mixed system. Two provisional props were used to hedge the stresses during the transitory phase, finally a in-place casting has completed the building process.

Fig. 6 - Bridge over river Piave Vecchia, 2001

4.5. Bridge in S. Donà di Piave – Venezia (in construction, end 2003)

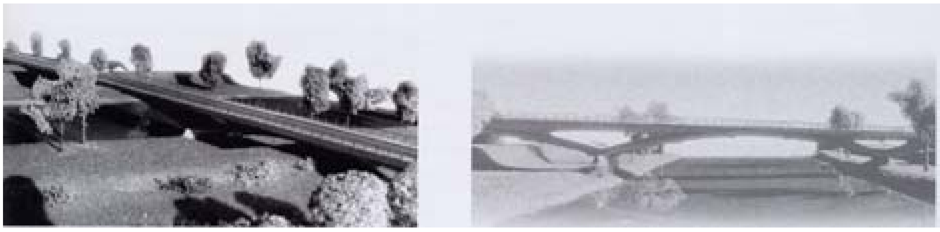


Fig. 7 – Bridge in S. Donà di Piave, in construction, end 2003

In the south part of the City of S. Donà di Piave, in the typical agricultural landscape that characterises this part of the "Pianura Padana", a new bridge is under construction, an evolution, in a bigger dial, of the arch structure type.

The bridge deck is 540m long and is composed of five lowered arches with a span of 100m from abutments. They decrease their length from the centre to the extremities.

Prefabricated reinforced concrete elements with rectangular section of 0,40m and 23m long are placed to build the arches. A second arches order is placed upon the other ones. They have the same radius of curvature, so the construction system, based on prefabricated reinforced concrete arch elements, is built with an industrialized building process.

The double arch order is made of prefabricated concrete arches, connected with a in-place casting and a suitable frame-work on the upper surface.

Each arch is composed of some elements: 5 in the main arch, 2 in the surmounting ones, that are connected on key stone and reins with an in-place casting, so as to constitute the whole development.

The deck has a "T" section with variable height, executed with a in-place casting, the provisional supporting structure formworks have been placed on the arches, just after their assemblement and connection.

After the construction of foundations through closed reinforced concrete diaphragms, on the arches springer, provisional props are placed to support prefabricated arched elements: 5 elements for the main arches and 2 elements for the surmonting ones.

These elements have been connected with a in-place casting on the upper surface of the arches, to restore nodes continuity.

In the second phase provisional supportings are placed on the arches, to hold the formworks for the deck casting; after the concrete ageing the final system is ready to support the elements on central arch and their following connection.

The work will be completed within 2003.

Fig. 8 - Bridge in S. Donà di Piave, in construction, end 2003

4.6. Bridge over the river Sacco, Sgurgola - Roma (to be constructed, end 2004)

Fig. 9 - Bridge over river Sacco, to be constructed, end 2004

The new bridge over the river Sacco forms part of a set of measures for reconfiguring the road communications due to the construction of the new high-speed railway line from Rome to Naples.The bridge is made of prefabricated high-performance concrete curved elements placed on provisional props and than connected by means of additional castings.

To balance the thrust, the ends of the arches are connected with diagonal struts to the deck, which thus acquires the static role of a chain.

Bundled strand anchors are provided at the ends of the deck so that the actions brought to bear on the ground are mainly vertical.

The bridge deck is approximately 132 m long and is composed of two arches with a span of 56 m and a rise of 5.6 m, that support a deck connected to the arches at the crown and at the abutments.

Each arch is composed of 20x5 prefabricated high-strength reinforced concrete curved blocks placed side by side to achieve a structure 10 m wide and connected by an in-place casting concrete top slab at least 25 cm thick.

This solution does away with the need for continuous formwork and the provisional supporting elements required are restricted to those needed to support the arch blocks; the number of said supporting elements needed over the length of the arch and the crosswise dimensions of each element have been defined so as to minimize the cost of their transport and assembly.

At the midspan of each arch, the deck slab is connected directly to the arches or to ribbing elements of various height supported by the arches; in line with the abutments and pier, the deck rests on prefabricated upside-down "T" beams placed side by side.

The foundations for the abutments and pier are to be laid on large-diameter (150 cm) piles in lengths varying from 16 m at one of the abutments to 33 m at the central pier.

At the abutment ends of the deck, tie-rods will be installed to balance the effects of eccentricity between the thrust of the arch and the chain action of the deck.

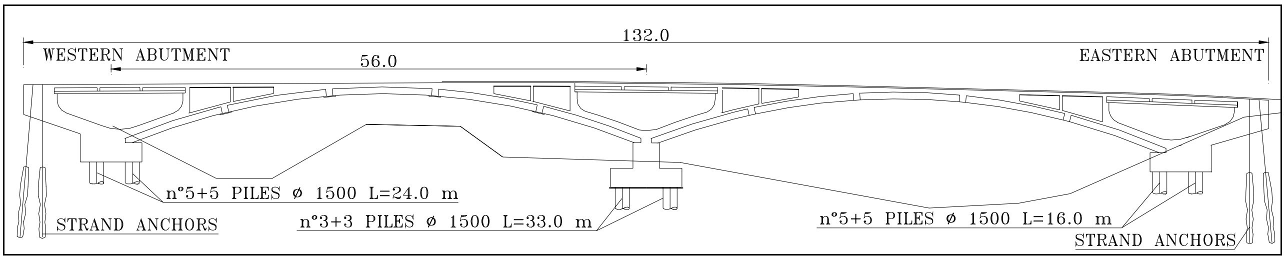


Fig. 10 - Bridge over river Sacco, to be constructed, end 2001

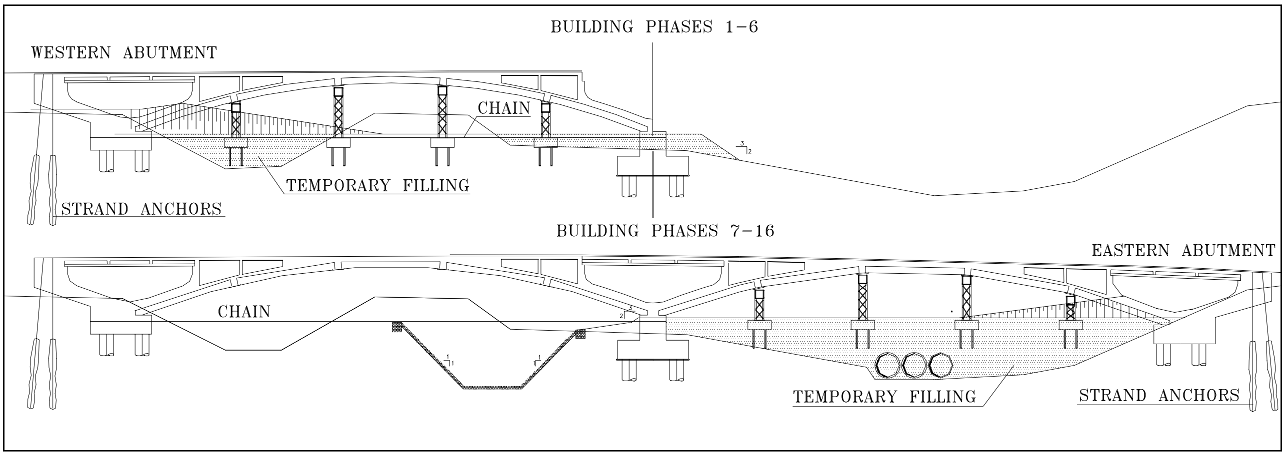


Fig. 11 - Bridge over river Sacco, to be constructed, end 2001

5. Conclusions

The structural conception and realization process are linked to the design process, as regards bridges, that influences the execution of a works; at the same time, the construction is conditioned by selections made during the project phase. Each single step involves both the preceding and the following process.

All these projects had the goal of an industrialized building process, able to respect the impact of new buildings on the environment. The design process has to adapt itself to different situations and dimensions, keeping the structural conception of a reinforced concrete arch bridge.

Technologies for industrializing the building process, using prefabricated elements that act as formwork and, integrated with the structure by means of in-place casting, become load bearing, make it economically viable to consider building types, such as the arch, because of the latter’s construction complexity and cost advantage.