English texts

THE ITALIAN SCHOOL OF ENGINEERING
Year LI, number 148, January-April 2016

History of Italian Structural Engineering. Rise and Fall

Tulllia Iori, Sergio Poretti

In the 1950s and 1960s Italian engineering got the international attention with a number of extremely original structural works. In the transition from the reconstruction to the economic boom, Italy had many chances to build great structures: the reconstruction of thousands destroyed bridges; the so called «Autostrada del Sole» (Motorway of the Sun); the Games of the XVII Olympiad in Rome in 1960; the 100th anniversary of Italian unification in Turin in 1961; hangars and stations in international airports; the Italian-style skyscrapers in Milan and Rome.

A real School of Structural Engineering took shape from this creative rush. How the paradox of a country that lagged far behind others in terms of technology but, at the same time, generated a particularly advanced engineering could be explained?

In order to answer this question we have to retrace our steps. The success of the Italian Style engineering, in fact, is the climax of a long experimenting process that started with the advent of reinforced concrete in the early 20th century and continued uninterrupted during the autarchy period and the Second World War.

The Italian School was univocally based on reinforced concrete, a material that has completely replaced metal structures since the beginning of the century. It was firstly used for great structures in the scientific sector, thanks to Camillo Guidi and Silvio Canevazzi first and Arturo Danusso and Gustavo Colonnetti later on. These two closely cooperated with the most important Italian agents for the Hennebique system and then with a particularly productive generation of design engineers. The collaboration between Danusso and Nervi gave birth to the Italian Style applied to the slender vault – this structural scheme, thanks to its shape-dependent resistance is able to bypass the weakness represented by the low concrete tensile strength. In Italy, Danusso, theorist and designer, pioneered testing on large scale models to calculate and assess structures. He created the Prove modelli e costruzioni, Model and construction tests, lab at the Polytechnic of Milan in 1931 and Ismes in Bergamo in 1951. Along this pathway, he met Nervi in the early 1930s. The result of this meeting was the first model (made of celluloid) for the Italian Air Force hangars in Orvieto. In those same years Nervi, with his own building firm, took over a parallel testing to offer a new manufacture method to produce reinforced concrete structures. The «Sistema Nervi» (Nervi System) resulted from the double need to eliminate costly formworks and comply with the very nature of the material and it was based on two brilliant expedients: structural prefabrication and ferrocemento. The system, refined throughout multiple minor experiences, was perfect for large roofs – a slightly corrugated or ribbed surface, an original reinterpretation of the slender vault, then became the typical Nervi's mark in his late architectural works. Prestressing would then regenerate reinforce concrete structures in those same years. In this case, stress effects were employed to save iron, on one hand, and to «train» concrete to oppose stress actions, on the other.

It was another scientist who spread this principle, Colonnetti – thanks to his efforts – first in autarchic Italy, then during his exile in Lausanne, and finally as the president of the CNR (National Research Centre) – the first bridges made of prestressed reinforced concrete could be built between 1949 and 1951. Due to postwar reconstruction and the following boom years, Italian engineering could finally apply the outcomes of processes that had been long tested in the previous years on real buildings.

This was the stage in which the Italian School of Engineering started its on-the-job training, and not just with its most famous protagonists' works, but with the contributions by a whole generation of designers: Nervi, Morandi, Krall, Cestelli Guidi closely followed by younger Zorzi, Musmeci, Carè and Giannelli, Galli and Franciosi.

The Autostrada del Sole, with its high number of bridges and viaducts, gathered the several personalities of the Italian School. Prestressed concrete bridges mainly crossed the widest of rivers – the wide concrete arch played a protagonist role on the Appennini Mountains stretch and its construction, divided into a multitude of small parts that small building firms had to deal with, represented an epic and spectacular version of the Made in Italy.

In the meanwhile, Nervi's architectural concept asserted itself as a leading one with the four masterpieces that he designed for the 1960 Rome Olympics, with his Nervi & Bartoli building firm.

In those same years Morandi, following his own pathway, developed an absolutely unique architectural style. The passionate and skilful way to use prestressing processes resulted into sophisticated and light versions of the basic structural schemes, to finally get to the cable-stayed beam on a balanced support, not made of concrete but steel. After the bridge over the Maracaibo's lagoon in Venezuela, the same element was then used in Italy in the Polcevera bridge in Genoa, the Magliana viaducts and the Fiumicino airport hangars in Rome.

In the 1960s the international fame of Italian engineering spread worldwide. But right when it peaked, the golden age of Italian engineering came to an abrupt end.

This was due to the sudden change of Italian production industry but it was also the effect of the more generalized and far deeper transformation of the structural engineering field.

Italian engineer could not find its own way in the new international framework. The generation of Nervi, Morandi, Musmeci, Zorzi, left a legacy of high-quality works but no heirs could go ahead with what had been done till then.

The Time of Ferdinado Innocenti's «Tube and Coupler»

Ilaria Giannetti

How were realized the reinforced concrete works of Italian structural art in the dimension of the handcrafted construction site? The construction process of the arch bridges of the Autosole or the Pier Luigi Nervi's Palasport domes based its challenge on a unique construction tool: the Innocenti tubular scaffolding.

Deus ex machina of this revolutionary construction tool was Ferdinando Innocenti, a blacksmith who, grew up in the paternal laboratory, patented in 1934 a revolutionary «device for uniting tubes of metallic structures», consisting of a clamping bolt with a T-shape head and a hinge. Of rapid assembly, portable, reusable and much more cost-effective than traditional timber framing, the system immediately established itself on the national building and still outstands among the steel products manufactured in Italy.

In the Thirties, it was applied to reinforced concrete construction projects, to set up imposing, temporary works to suit the needs for Fascist propaganda, and also for military use. In post-war years, following the establishment of a new company (Ponteggi Tubolari Dalmine Innocenti) founded by a team of structural engineers, the system was used in the construction of aweinspiring, dismountable and portable steel tube scaffolds designed to support viaducts connecting the new motorways.

In 1958, the transfer of the scaffold to be applied to the construction of the twin arch bridge across the Aglio river along the Autostrada del Sole was a pioneering technology performance. During the same months, even Pier Luigi Nervi used the pipe joint system to combine the precast and cast-in place components of his Palasport domes.

In the 60's, as the system had risen fast on international scene, construction gradually turned to more standardised solutions. Between 1961 and 1963, the pipe joint system was used in the construction of the last arch bridges connecting the Autostrada del Sole in the Florence-Rome.

That anticipated also the end of the cast-in place, reinforced concrete arch era and the dissolution of the distinguishing features of the Italian construction site that had been represented by Ferdinando Innocenti's creation.

«Trick» Structures. Eugenio Miozzi's Experimentations in Venice

Eliana Alessandrelli

In May 1932 construction of the arched Ponte degli Scalzi (Barefoot Monks Bridge) in Venice began. After the Rialto Bridge (dating back to the XVI century), this was the second bridge built to cross the Grand Canal with its span of about 40 meters, entirely made of white Istrian stone, without any reinforcement. The bridge was remarkably slender, only 0.8 meter thick at its crown. In order to construct such a thin structure, the designer Eugenio Miozzi employed an unconventional design and construction technique that he developed and called the «compensatory systematic lesion» method. It involved leaving open joints at the crown, which would close while lowering of the centre line of the arch, thereby shifting it into the middle third even in the absence of great thicknesses. Miozzi's «compensatory systematic lesion» method was the point of arrival of design experimenting that had started with Eugene Freyssinet's work and the use of hydraulic jacks to raise the centring of the bridge arch. From the mid-1920s onwards, Miozzi focused on the development of his method to control the position of the axis of the arch. He would have wanted to apply it to the Ponte della Vittoria (Victory Bridge) on River Piave in Belluno but could not do so. Only at the turn of the century was he able to convert theory into practice by employing the so-called «systematic deformation» method for the construction of the bridge crossing the Sojal brook in the Fassa Valley. The designer's masterful use of hydraulic jacks allowed him to eliminate parasitic effects in the bridge and to restore balance based on analytical calculations. Unfortunately the method, adjusted to different design solutions, showed its limitations, which Miozzi was able to overcome by referring to Volterra's distortions and developing the so-called «systematic lesion» method that he used in the construction of the Druso Bridge in Bolzano in the 30's.

Miozzi carried on his studies through the 30's, adapting himself to the restrictions imposed by the Fascist regime. As a result, the critical position of the arch centre line was controlled by recourse to the brick «vertebrate structure» technique, which was employed in the construction of the bridges spanning Rio Nuovo in Venice. Short-span bridges of that kind, apparently similar to all other structures crossing the city's canals, contained a trick that would anticipate co-action leading to the prestressing technique by applying Alessandro Antonelli's experimentations on reinforced masonry.

From Liberation to Reconstruction. Stories of Bridges

Ilaria Giannetti

The war that led to the liberation of Italy was fought to regain territory inch by inch. The road and rail networks were strategic objectives for both sides: the troops who were retreating and those who were advancing. Thousands of bridges were damaged and destroyed, tons of iron, bricks and concrete collapsed into the rivers. The «first aid» given to the structures, led by the Allied Corps of Engineers, was based on salvaging what could be saved. With improvisation, intuition and courage the «standard» procedures of the American manuals combined forces with the experience of the Italian artisans. «Surgical» interventions were made on the structures that had been bombed or blown up: hoisting, cleaning up, and rendering unusual combinations of materials and structural schemes. There was a cross-fertilization between the American method and the «know-how» of the Italian technicians. In the Sappers' language, new words appeared like «structuring» and «centering» (used to codify unusual procedures for stabilizing viaducts standing on masonry arches or the use of emergency ribs to support the most damaged arches), for which an appendix entitled «Unconventional methods» was added to the manuals. They contained descriptions of how to improve materials by using «salvaged» items; and detailed descriptions were made of unorthodox bridge launching procedures, like the «Italian style incremental launch» (where a «train» of beams are launched by stiffening the head beams to avoid the need to set up temporary noses).

The reconstruction that followed after a few months, made possible by US economic aid, was an unprecedented feat for Italian engineers and construction companies.

The railroad network had to be reinstated and the roads upgraded to keep pace with the economic recovery of the country. This is how the bold solutions tried out in the previous years came to maturity in a collective professional spirit. While the National Liberation Committee took on full powers, the front lines, abandoned by the Allied troops, were enlivened by new opportunities. Companies submitted bids for the tenders issued by the Ministry for Public Works with great enthusiasm, calling on engineers to cooperate with them. For engineers, this was the opportunity to demonstrate their technical skills and ability in the execution of construction work. There were cost constraints (funds still came through the Allied Military Government), a shortage of plant and equipment and steel was still requisitioned by the military. Cement was the only material for which the Allied Government could ensure supplies. These were the conditions surrounding the «counterbalanced» beams used by Riccardo Morandi over the river Liri, and for the «Maillart» arches by Arrigo Carè and Giorgio Giannelli over the river Nera and over the river Frigido, the «steelless vaults» by Carlo Cestelli Guidi over the river Arno, and for the «rotating semiarches» by Giulio Krall on the river Calore.

When the Republic was proclaimed in 1946, activities began for rebuilding the towns and their bridges. Here cost constraints and limited equipment were compounded by the special need to comply with «stringent aesthetic criteria»: Morandi and Krall, respectively in Florence and Pisa, designed two low-rise arches in reinforced concrete, «to provide a frame though which the hills and the town would be seen (…) in harmony with the monuments».

The final reconstruction of the bridges over the Po River was started. This was an enormous collective endeavour, where everyone's collaboration was needed. In Piacenza, the Dalmine company signed a unique proposal for the assemblage of steel tubular trusses with huge savings on materials.

In 1948, with the launch of the Marshall Plan, the 300 billion lire of revenue raised from the sale of goods from the United States, and entered into the State budget under the item Fondo Lire, constituted the basis for funds available on request to municipalities and companies. Infrastructure was the heart of the Plan for the economic recovery of the Country and was the means for physically receiving aid at the local level. This «new bridge» that appeared in all the Municipalities between 1948 and 1952 created new jobs, and the new wages fuelled the consumer market, and facilitated the transportation of commodities. Construction sites appeared everywhere (they were «Learning Worksites», «School for Construction Workers»); experimentation focused on reinforced-concrete bridges, with more or less audacious structural solutions, that could be produced by local firms employing unskilled workers.

In 1951, Italy's largest reinforced-concrete arch bridge was built (102 meters span) over the Calignaia river, south of Livorno. In only three years, the laborious advances of the Sappers was just a memory. Now, on the decks of the new large arches, the engines of Fiat cars would be heard as they journeyed towards the economic boom.

Calculating with Models. The Ismes Laboratory

Chiara Tarisciotti

In 1947, on the occasion of the tests carried out on a large model of the arched dam across the Piave river, the basis for the establishment of a modern experimental organization was laid. Following initial testing, the companies involved in the studies agreed on extending investigations to all building sectors. So in 1951 the Experimental Institute for Models and Structures was founded. Based on an idea by Arturo Danusso and Guido Oberti from Milan's Politecnico, ISMES was intended to carry out scale model-based investigations on large structures in order to promote technical and scientific development of the building sector. Research, and model-based research in particular represented the natural link between theory and intuition: a model was a valuable instrument for a designer since it helped him made statically-appropriate decisions, suggested him cost-effective solutions and checked calculation results. Based on a model theory, according to which two systems are physically similar if there is a geometrical correspondence between their points, modelling techniques distinguished between cases with a complete mathematical theory and those that could not be supported by a mathematical formula. In the former, the model was a powerful «stress calculating machine» (elastic models); in the latter, a structure's ultimate load-bearing capacity was evaluated with the use of structural models, exceeding the elastic limit up to the point of failure. The above model categories include most static and dynamic tests carried out at ISMES.

At a closer look, the enormous contribution made by P.L. Nervi's works to the development of construction technique and also another key aspect stand out. The fruitful relationship between Italian engineers and ISMES was the «x factor» that made the Institute renowned worldwide, but at the same time gave rise to structurally complex, hyperstatic structures that are symbols the Golden Age of Italian engineering.

«Foolproof and Incapable of Error». Automatic Computation and Structural Design

Gianluca Capurso, Francesca Martire

Since the Fifties, the electronic computer proved to be a powerful computational accelerator for the most common structural design issues. A contribution to its success also came from the introduction of matrix notation. At the National Institute for Automatic Computational Applications in Rome, one of the first computers installed in Italy made it possible to perform static analyses of the Pontesei and Vajont dams. In the following decade, the computer was used in the design of the US pavilion at Expo '67 in Montreal and of the Sydney Opera House (1958-1973). Codes based on finite element analysis made a fundamental contribution to the diffusion of machine calculation in civil engineering. With the advent of Sketchpad, the first revolutionary software for computer-aided design, the way for human-computer interaction was pioneered.

Since the early Seventies, Sergio Musmeci realized digital instruments would open new opportunities. Tensile structures seemed to be particularly suited to the practical application of his theories on linear programming, as shown by the 1972 Munich Olympic village.

Since the late Seventies, lightweight structures enjoyed short-lived success even in Italy, thereby stimulating research activities on the application of computer-aided calculation to the design of those big roofs. Giorgio Romaro and Bernhard Schrefler used specific codes for the construction of Milan's Palasport (1971-1976). On the occasion of the FIFA World Cup 1990 in Italy, Majowiecki designed some considerable tensile structures by developing advanced interactive graphic applications that he could use for computer-aided design throughout.

While in the Eighties the use of computers in engineering tasks spread in practice, academics focused on the development of new numerical form-finding methods for tensegrity and double-curvature roofs that could resist compressive forces. In recent years, computer-aided design has shown its dual nature increasingly, with research spanning the areas of computer graphics and digital morphogenesis.

The remarkable development of 3D printers and the latest innovations in computer-aided manufacturing technologies seem to fill the growing gap between the most advanced digital design results and construction methods that are evolving at a much slower pace.