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The Rise and Decline of the Italian School of Engineering

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Abstract

This paper tells the story behind the origin, rise and sudden disappearance of the engineering School in Italy in the 20th century. It was not an academic school as such, rather an actual design school that produced an extraordinary heritage of big structures. It was a golden age: by the mid-Sixties Italian structural engineering was recognised as one of the most prestigious in the world. However, just after the economic miracle, the school suddenly ceased to exist, and it has been completely forgotten. Even by historiography.

It is true that some of the leading figures are well-known: Pier Luigi Nervi was maybe Italy's most famous designer worldwide and even Riccardo Morandi or Sergio Musmeci enjoyed high popularity. But the school was the result of a more complex adventure undertaken by two generations of scientists, designers, contractors and builders. In the absence of a historical reconstruction, that collective story has become lost in the mists of time.

The SIXXI research (XX Century Structural Engineering: the Italian Contribution), funded by a European Research Council (ERC) Advanced Grant, was developed with the aim of tracing and telling that story to engineers, architects and everyone.
In the paper the story is proposed as a two-voice story: the first narrative voice tells about events, individual works, construction sites, significant episodes; the second voice (in italics) connects them to the unfolding of the entire affair.

This text is dedicated to the 43 victims of the collapse of the bridge over the Polcevera in Genoa, on 14 August 2018. It is not possible today to know the causes of the collapse: but we can say without fear that Riccardo Morandi is not guilty for it. He was the best Italian bridge designer, with few rivals in Europe. Blaming Morandi for the collapse is now a way to absolve ourselves for not being able to save a masterpiece of Italian engineering, an icon of Made in Italy, a structural jewel, causing unforgivable mourning.

Keywords:

History of Structural Engineering; 20th century; Italy; SIXXI.

Introduction

In the mid-1960s, Italian structural engineering suddenly leapt into the international spotlight. In a short period of time, considered the golden age for the entire Western world, Italy shifted from a state of backwardness, in which it had been mired for so many years, to one of fulfilled modernity. The most spectacular signs of this feat include reinforced concrete large structures from the post-war period and the successive years of the economic miracle.

Upon first glance, Italian structures do not reveal particularly innovative scientific or technological characteristics. On the contrary, they fit perfectly into the categories so clearly defined by modern structural typologies. For this reason they are immediately familiar. Yet, they also demonstrate a marked recognisability, introducing their own unmistakable intonation and standing out for their particular architectural physiognomy. This polarity, balanced between orthodoxy and national identity, is the true characteristic trait of the Italian School of Engineering. Not to mention its hallmark.

Hence, each time were return to investigate the identity of the first-rate engineering expressed by a late arriving nation such as Italy, two opposing curiosities guide us through a labyrinth of events and the tangle of documents: what are the foundations of the conformity of Italian structures within an international framework? But above all, to what internal factors of the country's history does it owe its uniqueness? [1]

From preunitary states to united Italy (1830-1890)

In Italy, modern engineering had already come into existence at the time of the preunitary states (before 1861). During the Napoleonic period and then during the Restoration, many corps of engineers were organized. Training was provided by suitable schools of engineering.

At first, the Italian engineer was considered a technical bureaucrat. He was a hydraulic engineer, a land surveyor and a civil architect. His business included the land registry, road construction, wetland reclamation, etc.

However, in the 19th century, the symbol of modern engineering was the large wrought iron structure. Like other countries, Italy was invaded by a host of suspension bridges. And as the Italian engineer had received no training on structural design, most were built by foreign engineers and construction firms. Some exceptions were the Real Ferdinando Bridge over the Garigliano River, the bridge over the Cecina River and the bridge over the Lima River, which were designed by Italian engineers.

Even the first railway lines were initially given on a concession basis to entrepreneurs from across the Alps. Even the Central Line, which ran through the Apennines and across several states, was designed by Jean Louis Protche, a Lorraine-born engineer. After the unification, things slowly changed. With the development of the railway network, imported facilities were complemented by an increasing number of works by Italian engineers and construction firms.

Alfredo Cottrau, trained in France but Neapolitan by birth, built with his Impresa Industriale Italiana di Costruzioni Metalliche (IICM) about 4,000 railway bridges in twenty years. As throughout Europe, the preferred solution was the reticular truss, which looked like a spaceship in the Italian agricultural landscape. Very few bridges survived, but the trend is immortalised in the extraordinary images of Achille Mauri, the King's photographer.

However, the transition from imported structures to typically Italian ones is demonstrated in detail by the sequence of railway bridges over the Po, the largest river in Italy. Until wrought iron came into use, a stable bridge had never crossed it. Following the unification of Italy, six large truss bridges were launched within a few years. And while the first four were still the work of foreign designers and construction firms, the last two - in Casalmaggiore and Cremona - were designed by Italians and built by the Società Nazionale delle Officine di Savigliano (SNOS).

Meanwhile, Italian scientists made a substantial contribution to the development of the theory of structures with the "energetic path" for the resolution of statically indeterminate structures opened up by Federico Menabrea and Alberto Castigliano, and also with the Graphical Statics method introduced by Cremona, the "Cremoniano". The most finished product of the virtuous science-construction skill

combination was the bridge over the Adda River at Paderno. Designed by Jules Röthlisberger, the Swiss technical director of SNOS, the magnificent fixed-arch bridge with its span of 150 m was calculated with the elegant method of the "ellipse of elasticity" by Culmann.

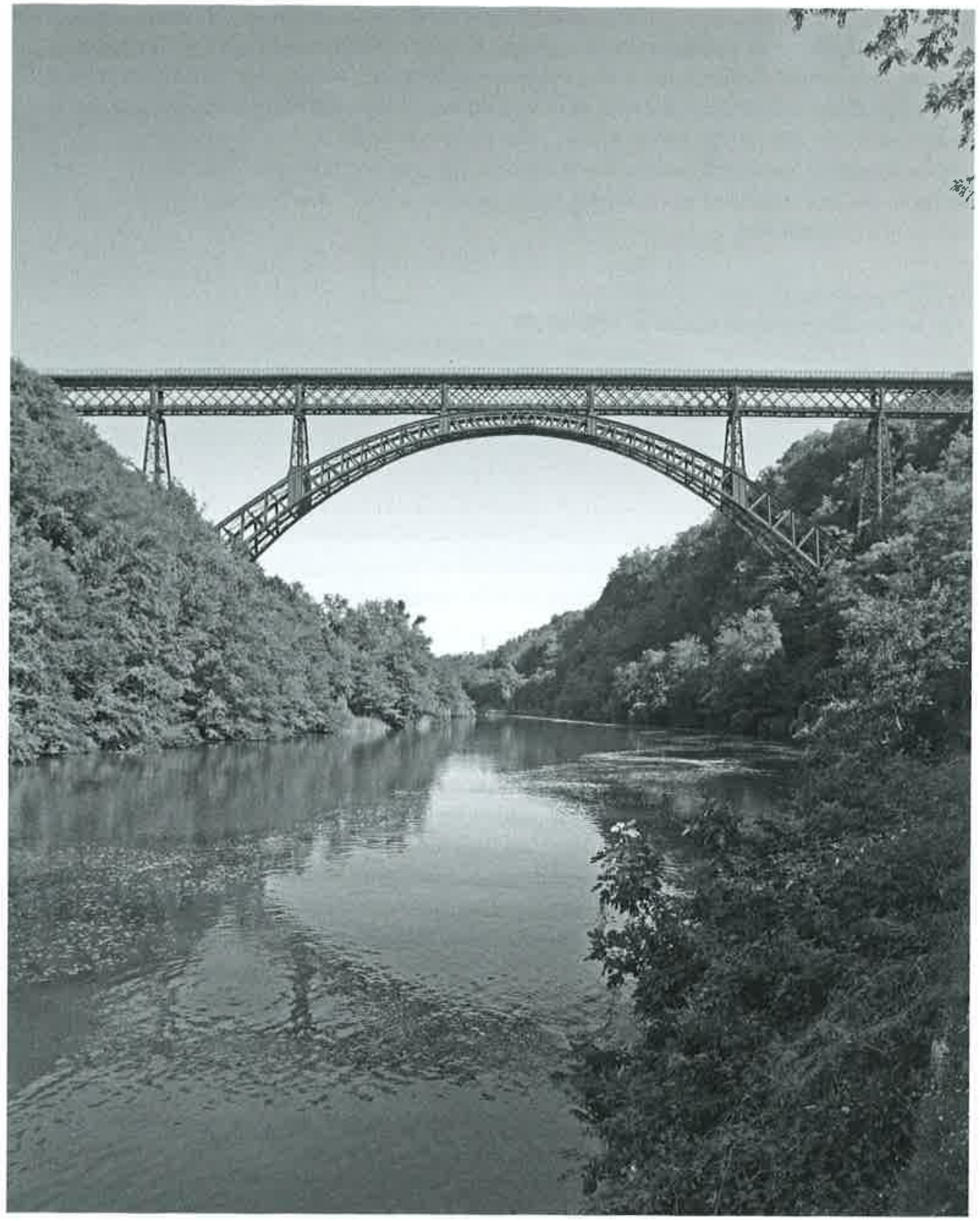

Figure 1. Railway bridge over the river Adda, Paderno. Jules Röthlisberger, Officine Savigliano, 1887-89. Photo: Sergio Poretti.

At the end of the century, Italian engineering did no longer depend on foreign schools but had not taken on its identity, yet. However, the foundations for the development of a native structural design school had been laid.

Being trained as an officer, the Italian engineer set a mental attitude that would remain in his DNA: discipline. Moreover, in Italian universities a solid scientific tradition, connected to the international network, was started. Collaborative practice between scientists and builders was established in the field. One single factor still hindered the take-off of a purely native school of engineering: the fact that metal construction was alien to the Italian milieu. Alessandro Antonelli's attempt to pave the way to an all-Italian "reinforced masonry" construction method for big structures turned out to be utopia (as the Mole in Turin, the tallest building worldwide in bricks and iron chains). The only option was to await the advent of a new material.

The advent of reinforced concrete (1890-1935)

Italy provided the breeding ground for the immediate and widespread dissemination of reinforced concrete. At the beginning of the new century, there was, however, an obstacle that had to be overcome: there is no evidence showing that the new material can also be used in big structures. The application of the conventional elastic theory, which was intended for a homogeneous material such as steel, did present difficulties. Scientists were initially sceptical but then sought to adapt the theory to such a heterogeneous material like reinforced concrete.

The dissemination of the new material in the field of building construction was facilitated by the two most eminent representatives of the discipline: Camillo Guidi, who closely followed the work of his pupil Giovanni A. Porcheddu, one of the most prolific agents of the Hennebique system; and Silvio Canevazzi, who worked in close contact with another agent of the same firm, Attilio Muggia.

As a result, the new bridges, like the one built over the Bormida River at Millesimo in 1902, had an agile exposed structure instead of the massive wall system. The construction sites, with their epic and experimental atmosphere, became a favourite subject for photographers. And Muggia's assistant, Nino Ferrari, did not hesitate to get women and children from his family to pose on the construction site of the bridge on the Magra River. Perhaps the most daring and spectacular bridge of the pioneering phase was the bridge on the Tagliamento River at Pinzano, which Giuseppe Vacchelli designed between 1903 and 1906 based on the use of another of the most important European patents, namely the Melan system.

The culmination of the introductory phase of the use of reinforced concrete is represented by the story of the Risorgimento Bridge in Rome, completed in 1911 to celebrate Italy's fiftieth anniversary. With its 100 m span, the arched bridge proposed to the City Council by Porcheddu set the world record at that time and also marked the transformation of reinforced concrete from a patented commercial product into a "free material". The design progressed through an adventurous series of attempts and discussions with the client. The final solution, which had to solve the major issue of the unexpected, very poor ground resistance (a kind of mud), was personally defined by Hennebique.

In the end, the final structure was composed of a very thin vault, reinforced by seven longitudinal spandrel walls supporting the deck. The figure was very thin and came down to 85 cm at its crown. Compared to the first solution designed by Porcheddu's technical office, the weight and thrust of the bridge were halved. Furthermore, the foundation had no slab; the abutment rested directly on special "Compressol" concrete piers, which were the true roots firmly anchored to the ground.

Despite the good results of the load tests, the bridge, if calculated by the elastic formulas, appeared in some places to be stressed beyond the limits allowed by the regulations. That gave rise to an endless debate that demonstrated how challenging it was to model the structure, suspended between the thrust-generating arch, the double cantilever and the variable-inertia fixed beam. Also, the behaviour of reinforced concrete beyond the elastic phase – which Hennebique seemed to have perfectly perceived – was not understood it would not be till the Thirties when plastic adaptation theory was developed.

Figure 2. Risorgimento bridge over the Tiber, Rome. F. Hennebique, G.A. Porcheddu, 1909-11. Photo: Sergio Poretti.

Meanwhile, World War One broke out and with the reconstruction of the numerous "Victory bridges", experimentation, now freed from patents, expanded to an entire generation of young engineers. Against that background, Eugenio Miozzi introduced advanced techniques, like "systematic deformations and cracks", to change the arch's pressure line; Giulio Krall, the scientific leader of Ferrobeton, the first general contractor for national reinforced concrete constructions, explored new static schemes and new construction methods.

During those years, Pier Luigi Nervi, who had trained in Bologna at the Canevazzi School, appeared on the scene. After a long apprenticeship in Muggia's firm, he led his first construction company to build some challenging structures, like Banchini Theatre in Prato or Augusteo Theatre in Naples. Although they were veiled by an eclectic architectural language, they allowed Nervi to see the remarkable potentials of reinforced concrete on the construction site. And when he built the Berta stadium and by happy chance left the dynamics structures of the terrace, the cantilever roof and the spiral staircase exposed, the news that Italian architecture had finally awakened spread all over the world.

Hence, the Italian School of Engineering emerged with reinforced concrete and remained strongly linked to it. That was the pioneering stage of reinforced concrete structures worldwide: when scientists worked

Figure 3. Victory Bridge over the river Piave, Belluno. E. Miozzi, 1925-26. Photo: Sergio Poretti.

side by side with builders, and often practice came before theory. At that time, "the object that does the science" (in Edoardo Benvenuto's words) was the arched bridge. Italian engineering was actively participating in this process and from the very beginning appeared like perfectly orthodox modern engineering.

Soon, however, the feature that would remain an Italian peculiarity appeared: in small-scale construction sites, the evolution of the arched bridge remained more connected to the Italian masonry tradition rather than to international steel construction.

Experimentation triggered by autarchy (1936-1944)

In 1936, the scenario suddenly changed: following the invasion of Ethiopia, heavy sanctions fell on Italy. Fascism proclaimed the autarchy regime. The scarce steel available in the country was now used by the war industry. The use of reinforced concrete, so far encouraged, was first limited and then, in 1939, banned altogether. The evolution of Italian construction underwent a sharp U-turn.

How did the engineering of long-span structures respond to autarchic restrictions?

In two ways: in the construction sites of the colonies and of the celebratory "Empire bridges", it reverted to masonry construction; in the laboratories, it projected forward by experimenting with new steel-saving techniques. The experimentation ran along two distinct lines, which would become the main lines of the development of the School. The first experimental line made the best of the "strength through shape" principle, thereby taking advantage of reinforced concrete being a shapeable material.

It was led by Arturo Danusso and developed by Nervi, who at that time invented a new, highly original construction system. Danusso stimulated designers to use their intuition to explore the world of new resistant forms and in 1931 established the "Model and construction tests" Laboratory at Milan's Politecnico, which from 1950 would continue its activities at ISMES (Experimental Institute of Models and Structures) in Bergamo. Following the same approach, during the autarchy regime and war years Nervi and his Nervi and Bartoli firm undertook a series of experiments that led him to reinvent from scratch the way reinforced concrete structures were to be built.

In 1936, the Italian Air Force entrusted him with the construction of two hangars at Orvieto. Nervi designed a structure formed by a complex web of inclined arches and to calculate it, he requested Danusso to make a model. The tests provided excellent results, but the construction proved costly because of the formworks. So when the Italian Air Force requested six more identical hangars, Nervi changed his strategy. And so it was that to eliminate formworks he invented "structural prefabrication". The structure was composed of many small pieces that could be prepared on the ground and then reassembled as in a large mosaic, and finally joined with in-situ concrete casts, thus restoring its monolithic aspect.

During the war, Nervi experimented on reinforcement and concrete percentages and ended up also inventing a new material. The idea was to hand spread concrete directly on a package of shaped wire meshes: that's how ferroconcrete originated. It was a homogeneous, ductile, perfectly elastic and resistant material that could be moulded without any formwork. After patenting it, when the Allies arrived in Rome in June 1944, Nervi built his first ferroconcrete structure: a small warehouse at the Magliana district. The whole pavilion was made of ferroconcrete: the walls and the roof, cleverly corrugated, were shaped to resist and were just 2.5 cm thick.

Figure 4. Magliana Warehouse, Roma. P.L. Nervi, 1944-45. Photo: Sergio Poretti.

However, the construction site proved also that making ferroconcrete entirely by hand on site was anything but an easy task. So, then, Nervi put together two 'tricks': structural prefabrication and ferroconcrete. The "Nervi System" came into existence from that combination.

But first things first. As already mentioned, there was a second experimental line, which relied on prestressing to save steel and at the same time to increase the static efficiency of the structure. Steel was not used to resist tensile stress but to prestress concrete, which thus became capable of resisting bending stresses by itself (or almost). That was Freyssinet's idea, disseminated in Italy by the Turin-born scientist Gustavo Colonnetti, for whom the "revolution in the art of construction" was a brilliant application of his theories on elastic-plastic behaviour and co-action states. He was very enthusiastic and in 1939 he developed a calculation system for pretensioned beams and registered a patent for prestressed beams with a variable section. But we were on the brink of war. Colonnetti was forced into exile and to continue his activities in the Italian university internment camp in Lausanne. There he met some of the engineers who would launch the new prestressing technology in Italy: Franco Levi, Aldo Favini and Silvano Zorzi. When Colonnetti was called back to Rome and nominated president of the National Research Council (CNR), he became one of the great leaders of Italy's reconstruction: prestressed reinforced concrete took off to a flying start. A major contribution to that success came from the "Research centre on states of elastic coaction", which he had established within the CNR.

Facing autarchic constraints, the School took on its final look, which included two lines: an empirical line that would produce an original version of thin shell (and prolong the life of the arched bridge), and an analytical line that would lead to early development of prestressing.

Thin shells and prestressed concrete were the two strategies that marked the revival of reinforced concrete structures worldwide. That confirmed Italian engineering was part of the great international family of modern engineering.

Underlying that orthodoxy, there was the firm rooting in Nineteenth Century positivism. Rationality is based on science. Embodying that principle, the structure became the most effective symbol of progress.

The Italian School was no exception. But, at the same time, it was growing in a unique environment dominated by humanist culture and Catholicism. That supremacy was recognised by the very engineer. Scientists were the most fervent supporters of the superiority of spiritual vision. Danusso showed striking similarities between the plastic adaptation theory and social justice. Colonnetti considered the engineer as 'God's helper'. Designers, being more sensitive to the laical precepts of neo-idealism, preferred the principles of ethics to scientific rigour.

We will see in the following how those (and other) humanist contaminations had a direct impact on the languages the School would express in its mature phase, thereby creating its uniqueness.

Post-war reconstruction (1945-1955)

The conflict that led to Italy's liberation was a territory war. Thousands of bridges were destroyed by the retreating German troops and Anglo-American bombings. The temporary and partial restoration of the bridges by the Allies on their way was an epic preamble to the final reconstruction. It was an emergency engineering intervention, which concerned first of all the railway bridges. The operations were coordinated by the Railway Construction Troops following the Allied Army Corps of Engineers, and also made use of local workers.

The transition from war emergency to the permanent reconstruction of railway and road bridges occurred gradually as the country was freed.

The collaboration among the Allied Army engineers, the Sappers, and the Italian technicians, which had begun during the war, continued in the early post-war years. In the end, the complementarity between the former's high specialisation and the latter's resourcefulness was particularly fruitful. So much so that American manuals would include an annex on "unusual methods", which described the new and unorthodox construction site procedures, including the "Italian-style" incremental launch.

In addition to the hundreds of damaged railway bridges, almost three thousand road bridges were to be rebuilt nationwide, most of which were located between the Gustav line and the Gothic Line. So there was plenty of work for all engineers. And room for all bridge types.

The very first prestressed concrete beam bridges appeared: designed by the young Zorzi (on the Mucone river) or by the more mature Morandi (on the Elsa river). Among the experimental structures, a new, ultra-light version of the arched bridge stood out: the "Maillart type". As known, the thin arch with a stiffening deck worked like an inverted suspension bridge. The arch, so thin as to be devoid of bending stiffness, was only compressed. The deck absorbed the bending moments. It was imported into Italy from Switzerland by two scientists: the Rome-born Giulio Ceradini, who when in Zurich had monitored the Maillart bridges under the guidance of Mirko Roš, involved his peers Arrigo Carè and Giorgio Giannelli in the bridges over the Nera and Frigido Rivers. The Neaples-born Adriano Galli, who was an intern at the same Swiss laboratory, designed the bridge over the Corace River and the bridge over the Vernotico River at Gragnano together with young Vincenzo Franciosi.

While the huge work by engineers on railway lines and roads went unnoticed, a lively debate among historians, restorers and architects arose on the reconstruction of urban bridges. It was the same story every time: restoring the former bridge (especially if old) or building a new modern one? When the thesis for a new bridge prevailed, it was once again the extremely low-rise arched bridge, which drew the interest of both scientists and designers to the now distant history of the Risorgimento Bridge. It occurred with San Nicolò Bridge by Morandi, the first to be rebuilt in Florence where all the bridges (except the Old Bridge) had been destroyed on the night of August 3, 1944. It also occurred with the central Middle Bridge in Pisa, designed by Krall and Cesare Pascoletti.

From the very beginning, reconstruction made use of the amounts received from the United Nations, the UNRRA, and especially the United States. To complete reparation of war damage and start the country's rebirth, in 1948, the ERP programme, better known as the Marshall Plan, was implemented. Once the emergency was over, priority was given to certain landscape features with the intent to restart tourism.

The doubling of the Aurelia State Road in the section between Albissola and Voltri was designed just like a tourist motorway. To win contracts, businesses hired the most talented designers: Morandi, with several different firms, built, among others, the Arrestra and Lupara Bridges.

On the other tourist motorway, the Naples-Pompeii-Salerno, the Maillart bridge was a success. Antonio Benini and the Swiss-born Ernst Schmidt (a collaborator of Roš) designed a beautiful sequence that culminated with the bridge crossing the Caiapha's valley with its 130-m long span.

Even Nervi played a major role in post-war reconstruction. By combining prefabrication and ferroconcrete, he proceeded to the final testing of the Nervi system. After some minor works, in 1947, he tested the system on the Salon B at the Palazzo delle Esposizioni in Turin and determined that it was suitable for long-span structures. The barrel vault with a span of almost 100 metres was made of precast ferroconcrete segments, 4 cm thick, prefabricated on the ground, placed in situ with the use of Innocenti scaffolding and joined with in-situ concrete casts. The structure, which was then also reported in numerous international journals, revived the fame that Nervi achieved in the Thirties. It was the basis for the many masterpieces of the boom years.

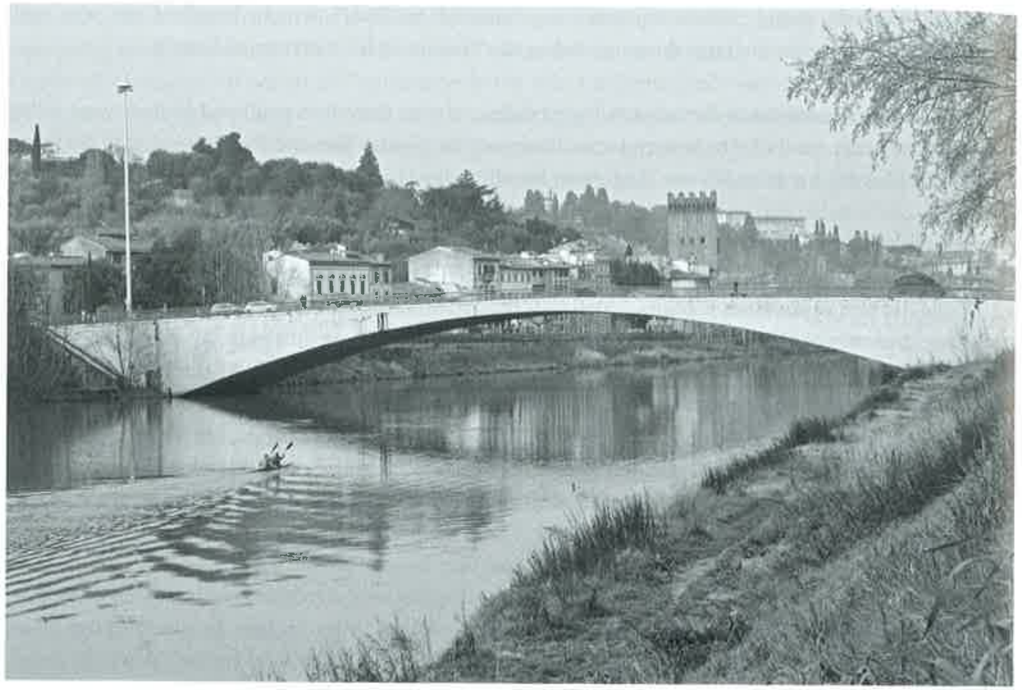

Figure 5. S. Nicolò Bridge over the Arno, Florence. R. Morandi, 1947. Photo: Sergio Poretti.

By participating in the post-war reconstruction, the School entered its 'adulthood'.

While the national debate focused on urban and architectural strategies, the engineers' reconstruction flowed its own track quietly. (It was also due to this discretion that it later remained excluded from historical reconnaissance.) However, that was a crucial time in the history of Italian engineering, which - through that exceptional feverish activity - acquired a collective and national dimension.

Indeed, the professional world was involved "en masse" in the gigantic work of restoration and upgrading of infrastructures. Domes and bridges, which had always been "specialised'" subjects for the chosen few, became ordinary professional commitments for two whole generations of engineers.

The first generation, including scientists like Colonnetti and Danusso, as well as designers like Nervi, Morandi, Cestelli Guidi and Krall, finally had the opportunity to apply the results of the experiments carried out during the autarky and war period.

The second generation, including their pupils Levi, Pizzetti and Oberti together with young Zorzi, Carè and Giannelli, Galli and Franciosi, as well as Musmeci, went directly from university classroom to the construction site.

From reconstruction to the economic miracle: The Autostrada del Sole (1956-1964)

Rebuilding the infrastructures got Italy's economy moving again and relaunched tourism.

With this momentum, the operation continued with a great plan that took Italy towards the economic miracle: the construction of the motorway network. Eight years – between 1956 and 1964, were sufficient to build the nearly 800 km of the Autostrada del Sole, or Autosole, the Motorway of the Sun, which included about 400 bridges. According to the design by Francesco Aimone Jelmoni prepared first for the SISI (a "study partnership" whose partners included Eni, Fiat, Pirelli and Italcementi), all bridges were of the same kind: reinforced concrete parabolic arched bridges of limited span.

However, Jelmoni's projects were only the basis for the tenders. Firms that could not win more than one section - usually 3 or 4 km long - were called for the final design; to be competitive, they had to choose the best engineers. In addition, prefabrication was rejected to employ as many workers as possible: the focus was on cast-in-situ reinforced concrete.

The first issue was crossing River Po in the section between Milan and Bologna. Zorzi solved it by using a sequence of 16 simply supported beams. It was the first major work built with prestressed reinforced concrete, which finally cleared the way for its use in Italy. When the Milan-Bologna section was opened to the public, even the *Transappenninica* works were well advanced. In the Setta Valley, the Sogene construction firm built the La Quercia viaduct and the arch bridge over the Sambro River, with which Morandi put his signature on the Autosole.

Continuing south, the Merizzano and Gambellato viaducts were contracted out to Ferrobeton. The designer Krall proposed a particular sequence of very elegant arches.

However, the largest arch on the Autosole is the Aglio viaduct with its 164 m span, a record in Italy at that time. The design was by Guido Oberti, one of Danusso's pupils and head of ISMES. The sequence of viaducts on the Volpe, Poggettone and Pecora Vecchia rivers, right between Emilia and Tuscany, featured the most beautiful curve. The Garbarino Sciaccaluga Mezzacane firm had the collaboration of Carè and Giannelli. The structure was broken down into six parallel planes, with pylons panelled like sheets of paper.

Meanwhile, the construction of the Naples-Rome section was advancing. The last section connecting Florence to Rome featured other signature bridges: the San Giuliano viaduct by Cestelli Guidi, a portal arch spanning 100 m; the bridge over River Tiber at Attigliano designed by Morandi; the thin arched bridge over the Borro Caprenne River by Carè and Giannelli. However, the most beautiful bridges were the last ones to be completed. They were both designed by Zorzi and stretched across River Arno. The first bridge was located near Incisa and consisted of a two twin prestressed concrete portal arches. The other bridge was located at Levane and was a sumptuous polygonal arch of ordinary reinforced concrete spanning 134 m, designed according to the funicular load system. It was that only bridge to be named after the 'father' of the Autosole, Giuseppe Romita, the Minister of Public Works who strongly wanted the road and the who died in 1958 before he could see his bold project become a reality.

In the miracle years, the School reached its peak and joined the world's engineering elite.

Italian engineering as a whole was involved in the epic undertaking of the Autosole, and its two lines can be clearly seen in the numerous bridges designed one by one.

Figure 6. "G. Romita" bridge over the Arno, Highway of the Sun, Levane. S. Zorzi, 1962-64. Photo: Sergio Poretti.

Prestressing consolidated as a proven, developed technology to build the endless viaduct stretching across the great rivers of the northern plains. Over the Apennine Mountains, the great arch made its swan song with record spans. However, if we want to understand the reasons why the motorway expressed the Italian character of the School, we must imagine the works sites. Despite its territorial scale, the motorway consisted of many handmade pieces: it was a giant, collective craftsmen's work, just like a Gothic cathedral. Conducted by small firms, the construction sites were epic undertakings.

The "prima donna" was the Innocenti scaffolding. The "wonderful web of steel tubes arranged in a fan" appeared one after the other while going up the motorway.

And, if the astonished spectator of the time was lucky, he could watch the epic scene of one of the colossal scaffoldings being moved from one lane to the other with simple hand-operated winches (as disassembly and reassembly would take too long).

Hosting of major international events: Rome Olympic Games and Italia '61 (1956-1964)

Italy's collective engineering work par excellence, the Autosole, lacked the support of Italian most important protagonist, Pier Luigi Nervi. However, during the same years, his work was seen worldwide through the television images of the 1960 Rome Olympics. Following the construction of the Motor Salon in Turin, Nervi had the widest recognition in the international arena. But his definitive consecration as an engineering master of the 20th century was to come between 1957 and 1962. For the Olympics alone, the 70-year old engineer completed with his small construction firm four large works in just four years: the Palazzetto dello Sport and the Flaminio Stadium in the Flaminio district, which included the Corso Francia viaduct, and the Palazzo dello Sport in the EUR district.

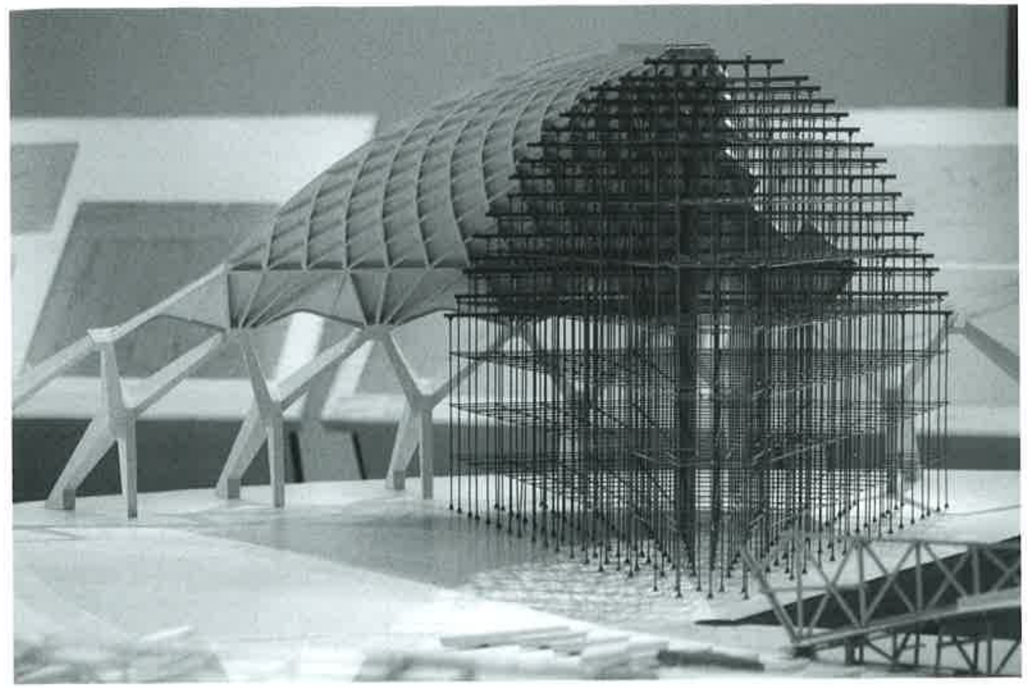

Figure 7. Little Sport Palace, Rome. P.L. Nervi, 1956-57. Model built for the monographic exhibition on P.L. Nervi in MAXXI Museum, Roma, 2010. Photo: Sergio Poretti.

The Palazzetto dello Sport was the first Olympic stadium to be completed.

The project was basic: a low, spherical dome, 60 metres in diameter, supported by 36 radial inclined struts. The dome, smooth on the outside, looked inside like an embroidery of crossed ribs. The construction site was an exemplary application of the Nervi system.

While the foundations and the outer struts were built on-site, the mosaic pieces that would make up the dome were prepared on the adjacent land. The spherical dome was broken down into 1,620 rhomboidal tiles to be assembled on site. The duplicate construction site allowed halving the construction time, and it was the strong point of Nervi's structural prefabrication.

The tiles were made of ferroconcrete and were small, 2.5 cm in thickness, easy to stack and light to carry. A dome section corresponding to 10 degrees was prepared on the ground as a template to be certain of the geometric modularity between the small tiles and the large double-curved dome. On such a template, the 13 tile prototypes were prepared: the "grandmothers". Within the grandmothers, 2 or 3 reversed counterforms were created: the "mothers". They were then used by several teams of workers to produce 108 blocks: the "daughters" (identical to their respective grandmothers). In the peak construction periods, the workers prepared up to 30 daughters per day. To build the dome, a light Innocenti scaffolding was rented for two months: it took 30 days to assemble the puzzle, then in-situ castings, in the gaps and ridges to restore the monolithic nature of the roof.

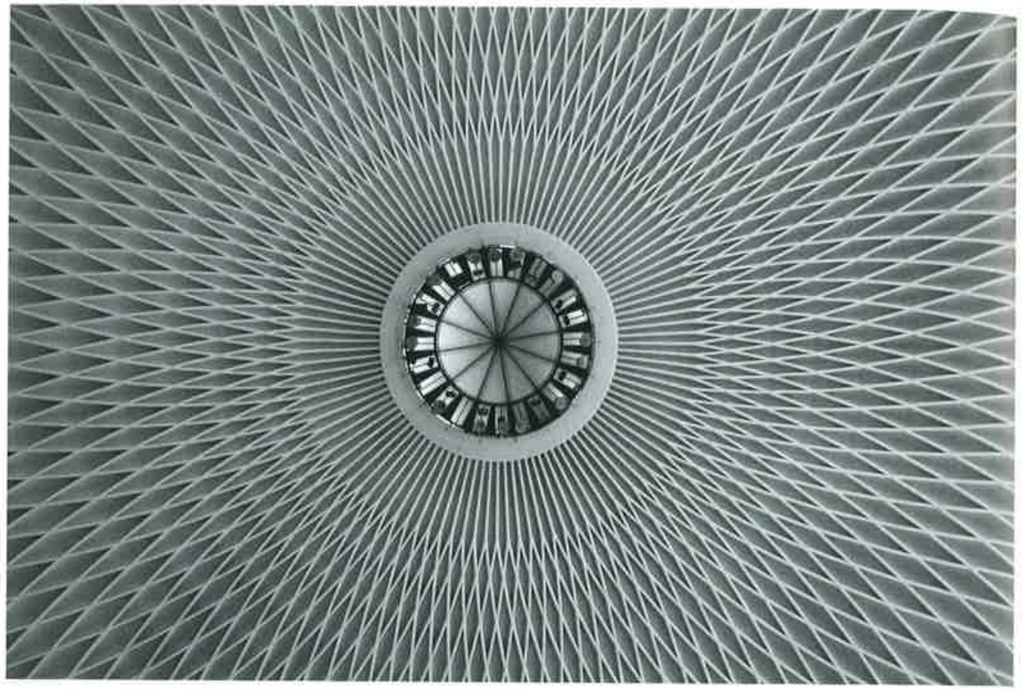

Figure 8. Little Sport Palace, Rome. P.L. Nervi, 1956-57. Photo: Sergio Poretti.

While the Palazzetto dello Sport was being completed, Nervi was also awarded the contract for the construction of the Flaminio Stadium. Here the ring-shaped frames and prefabricated stands were left exposed; the cantilever roof was an elegant ribbed surface that is reduced to a line at the free extremity. Simultaneously works began on the Palazzo dello Sport. It was a large-scale application of the Nervi system: the great dome was rippled with 144 ferroconcrete waves. During the Games, foreign critics would be enchanted by the extremely light structure. The image of young Cassius Clay with the gold medal in the boxing light heavyweight division around his neck, against the gorgeous dome, would astound the world.

When President Gronchi declared the Games open, preparations were already in full swing for another occasion of international appeal: the celebrations for the centenary of the National Unification in Turin.

Three structural works were planned: The Palazzo a Vela designed by Levi with Nicolas, the Alweg monorail designed by Morandi, and the Palazzo del Lavoro. The tender for the latter work was again won by Nervi, who was the only one to guarantee compliance with the very tight timeframe. So he was forced to give up his most distinctive inventions and to decide for a roof made of 16 spectacular steel umbrellas supported by huge, reinforced concrete, central struts. The enormous radial struts were made by the Antonio Badoni firm of Lecco, that had been working forever with Gino Covre, the forgotten designer, a real champion of Italian metal structures.

If the international community recognised the boom of an Italian School soon, this was because the structural languages that it expressed looked familiar and original at the same time. The most important was the one derived from the Nervi System. Looking at the structure, you can see the tension flow: the image describes in detail the relation between form and static behaviour.

So far, it is one of the many versions of the 'natural' language, which was very popular among thin shell. What then makes Nervi's domes so unique? The minutely undulated, corrugated and ribbed shape. The thin shells made by others (as Torroja, Candela, Isler...) are all smooth. Nervi's complex shapes would be too expensive for anyone. What makes them, paradoxically, economical is the Nervi System. Therefore, the language originality arises from an endogenous factor: the ingenuity of crafted workmanship, which goes back to the tradition of great Italian builders. That's one of the consequences of the humanistic vocation of Italian engineering, which looks to its own past with admiration: Nervi had the book by Jean Gimpel, "The Cathedral Builders", by his bedside and had a true devotion for the manufacturers of great masonry domes.

Morandi's invention (1956-1964)

Riccardo Morandi took part in the great achievements of the economic boom with continuity while remaining aloof. Actually, during those years, he was following a very personal path, which led him to define his own, unmistakable structural and architectural style. From the very beginning of his career, Morandi focused on the design of lighter and more essential structures, even by taking advantage of the magic of prestressing. Hence, he revised the basic structural types (the Gerber beam, the 2-pin portal frame, the balanced beam, ecc).

Morandi's strategy relied on a few key points.

Fragmentation was the first. Like Nervi, Morandi broke down his frames and beams into small segments to be prepared on the ground: however, they were conceived as mechanical pieces that combined through cables and anchoring systems, entering into coaction. He broke down also the static system into stand-alone elements, each "detached" from the other structural components: see, for example, the two semi-arches of the bridge over the Lussia River or the slanting pillars supporting the roof of the new pavilion at the Turin Expo.

Balance was the second key point of Morandi's approach. Not one of his mature works is without a counterweight, be it: a true load placed on the bridge abutments to reduce mid-span bending, as in the Amerigo Vespucci Bridge in Florence; or the inclined struts that counterpush the giant arch to reduce thrust by approximately 10% (which is by no means insignificant) as in the viaduct on the Fiumarella River. Furthermore, the prestressed lower ties of the bridge for the Via Olimpica, which create on the beam a moment opposite to the one determined by the load. Last but not least, prestressing, the most effective balance, that Morandi also used to orchestrate real magic in the middle stages of the construction site.

Fragmentation and balance were two ways to converge towards the ideal of uniform strength. A major contribution to achieving that goal was also made by the decision to use a single material for the construction of all structural elements so as to obtain maximum uniformity of efforts and deformations and, last but not least, to form structures of homogeneous shape.

The triple approach based on lightness, balance and uniformity was the basis of the structural system that can be regarded as the culmination of Morandi's design process: the cable-stayed "homogenised" structure.

The first example was the magnificent bridge across the Maracaibo lagoon, with its 9 km span the longest in the world. As a result, Morandi acquired an international reputation paralleled only to that of Nervi.

Besides the usual fragmentation of the pylon and the Gerber deck into linear elements, the system also featured the A-frames and ties, which improved the slenderness of each part, thereby making the overall structure more imposing and impressive. The originality of the cable-stayed structure lies in the use of reinforced concrete. Morandi was so fully aware of this aspect that in his later Italian works - the Polcevera bridge, the viaduct across the bend of River Tiber at the Magliana district, the hangars at Fiumicino airport - the use of concrete could finally include the entire structure.

Even the cable-stays were made of concrete unlike the conventional steel ties made to withstand tension. In Morandi's version, the stay was composed of a bundle of steel strands, wrapped by a shell of prestressed reinforced concrete. Internal cables bore alone the weight of the bridge (the permanent load). However, live loads would make them stretch too much; hence, the shell around the cables was put into compression by a second tensioning, just enough to avoid tension under the action of live loads.

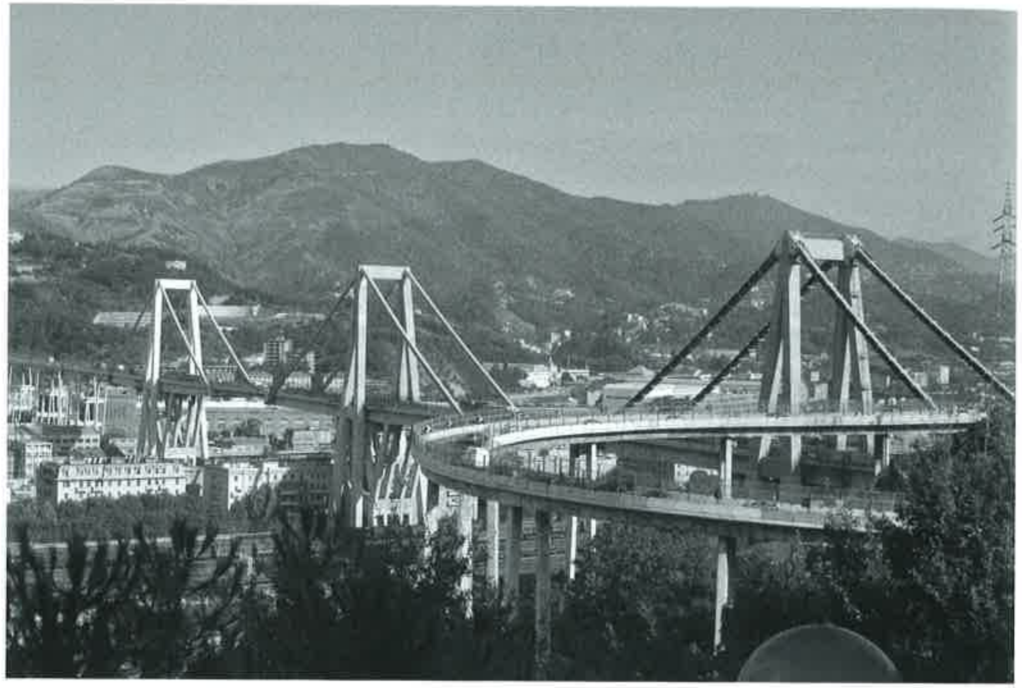

Figure 9. Polcevera Bridge, Genova. R. Morandi, 1960-67. Photo: Sergio Poretti.

The "homogenised" cable-stayed bridge is another signature of the Italian School of Engineering. This structure speaks of itself: it shows its own static functioning. However, while Nervi's resistant forms exhibit the flow of internal tensions, Morandi's figure represents the balance of external forces, the weights and counterweights, thrusts and counter-thrusts.

The scientism of balanced figure opposes the naturalism of resistant forms.

The cable-stayed bridge was just well known in the Fifties. And again the originality, the Italian spirit, is to be found in the way of construction.

German designers made cable-stayed bridge entirely of steel. Morandi's invention was to made it entirely of prestressed reinforced concrete. Even the stays were made with that. That was the new and

surprising aspect: the typical lightness of the cable-stayed system was embedded in an on-site moulded structure of a substantially masonry nature. A hand-made structure. With such a sophisticated craftsmen's work, Morandi's language speaks to us once again about Italian modernisation but from a particular point of view: while the dome of "master potter" Nervi came under the classical craftsmen's tradition, Morandi's structural mechanical metaphor fell into the visionary genre that ran through the whole story of Italian modernism, triggered by Antonelli's reinforced masonry and re-launched in great style by futurism.

That is another consequence of the humanistic dimension of Italian engineering: being close to an all-around artistic movement as futurism was the driving force, not only for Morandi, to develop a special sensitivity for the figurative aspect of the structure.

The disappearance of the fireflies (1965)

In the early Sixties, the popularity of Italian engineering spread throughout the world.

Nervi's dome earned space in women's magazines. Morandi's cable-stayed structure was one of the most prominent examples of the "Made in Italy" and was reported on multinational business magazine as "Fortune". Through the new-born television, those structures let the world know the Italian miracle. At the "Twentieth Century Engineering" Exhibition at New York's Museum of Modern Art in 1964, the very restricted selection of world icons included a high number of Italian works.

But in the mid-Sixties, at the peak of its success, the School suddenly died out. With the end of the miracle, the School disappeared from the scene, too. The engineers' offices closed down one after the other. The cultural milieu, in which the multi-talented designer had grown up, dispelled. Specialisation was no longer to be postponed. Very low-cost manpower was no longer available, an essential condition for the survival of small-scale work sites. With the advent of the computer, the way structures were calculated changed. In the large-scale project sector, the shift was soon to be seen. The arched bridge was replaced everywhere by the girder-span viaduct with very high piers, with extensive use of industrial prefabrication. Economic needs and anti-seismic regulations were now the prerequisites on which to design structural and architectural works. Almost overnight, big structures were no longer individual works by a single designer but the impersonal product of a multi-specialised team.

The shift was certainly not limited to the world of construction.

On a wider scale, engineering was led into a crisis sweeping every sector at that time. It was a turning point: overnight, the tradition of material culture that had kept abreast during the twenty years of fascism, that was revived by reconstruction, that had triumphed during the economic miracle, was washed away by the wave of general standardization that submerged the Country.

Pier Paolo Pasolini was the first intellectual to blame the change, which he called a real "genocide" of Italian material culture. He did that in 1975 with the beautiful metaphor of "the disappearance of the fireflies".

"In the early Sixties, because of air pollution, and water pollution in the countryside (our blue rivers and limpid canals) fireflies began to disappear. This was a stunning and searing phenomena. There were no fireflies left after a few years. Today this is a somewhat emotional recollection of the past—a man of that time with such a souvenir can no longer see himself young among the young of today and can therefore

not have the wonderful regrets of those times. That "something" that happened ten years ago I shall now call "the disappearance of the fireflies".

The diagnosis, which at that time drew everyone's irritation, appears today as a reading by a clairvoyant. Certainly, the multi-purpose engineer was part of the world whose disappearance Pasolini blamed.

Posthumous masterpieces (1965-1980)

The decline of Italian engineering was enhanced by the trails left in the wake of the golden age, from which some memorable, 'posthumous' masterpieces were produced. Among the numerous works made by Italian engineers abroad, those designed by Nervi outlined the figure of the star-architect ante litteram up to the late Seventies. Every country would like to have a Nervi work. In structures like the bus station in New York, San Francisco's Cathedral and the Italian Embassy in Brasilia, the signature elements of the Nervi system could be seen.

However, in overseas works, the construction was contracted to local firms, which applied usual reinforced concrete techniques. Given the circumstances, the Nervi system, which was created and developed within the Nervi and Bartoli company, was exported in its purely formal effects and ended up becoming a style: the so-called Nervi style.

The same shift was to be found in part in the latest works built in Italy. If there is a work in which the Nervi style received its final consecration, that is the Audience Hall in the Vatican City.

Figure 10. Viaduct over the river Teccio, Cadibona, Highway Turin-Savona. S. Zorzi, 1976. Photo Sergio Poretti.

Then there is the solo endeavour by Silvano Zorzi. He was the first to realise that Italy had to be freed from the restriction of the scaffolding, as has long been the case in most industrial countries. And hence, that one had to accept the disappearance of the arch and the inevitable hegemony of the girder-span viaduct with high piers. However, Zorzi could not accept that this would necessarily involve depersonalization of the structural work. And so, in the latest-generation viaducts, he made a desperate attempt to sublimate simplicity of the viaduct with multiple piers. So he focused his design efforts on carefully drawing each element. The result was simple and essential, but extraordinarily elegant, structures like the urban viaducts in Milan or the Gorsexio, Teccio and Fichera viaducts.

Zorzi applied a "structural industrial design" based on a sophisticated static solution, which only a great prestressing expert like him could produce. It was a constructive design too, as he replaced the traditional scaffolding with proto-industrial machines that preserved casting on site: the cantilever forming traveller system or self-launching movable scaffolding. He used them to build one of Italy's most beautiful twentieth-century bridges, the virtually unknown Pinzano Bridge over the Tagliamento River, a three-hinged frame with 163 m span.

Finally, there is a work in which the adventure of the Italian School found its conclusion and its apotheosis: the bridge crossing the Basento River by Sergio Musmeci.

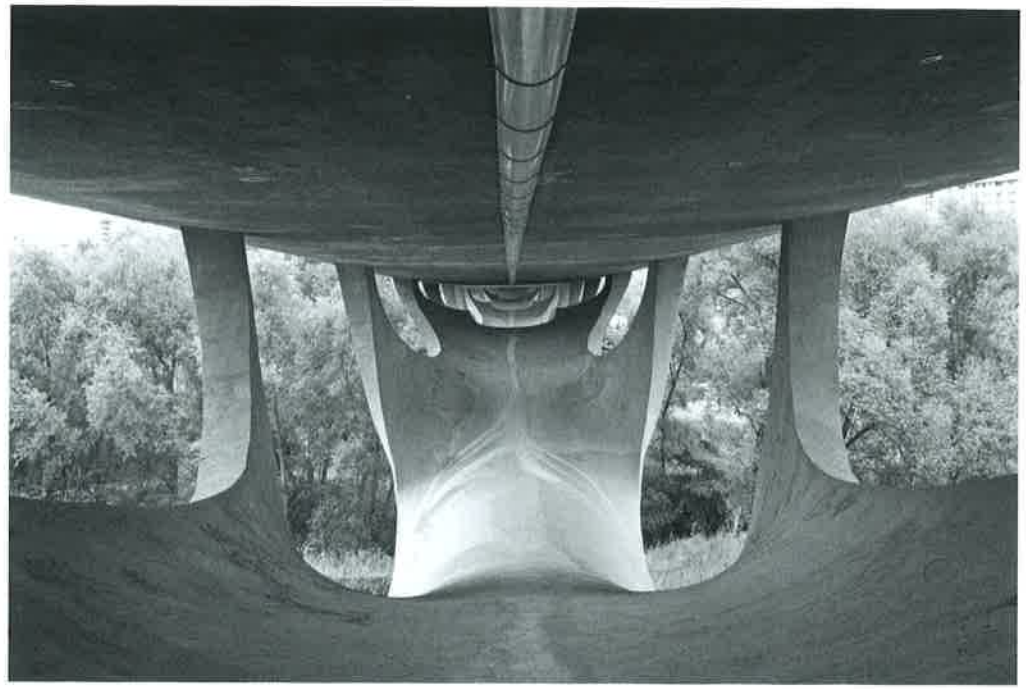

Figure 11. Bridge over the river Basento, Potenza. S. Musmeci,1971-75. Photo: Sergio Poretti.

The "unnamed" form of the shell was designed by applying a kind of theorem analytically and with model tests: once the constraints and loads were set, the unknown factor to be calculated was the form. If the best form, the lightest form, the "minimal" form, the mathematical problem had to be determined.

In order not to affect the purity of the scientific calculation of the form, it was necessary, however, to get free from every influence of habits. All of them: the usual structural schemes, the boundaries of classical geometry, but, above all, the way of construction (a scandalous position in a master builder's environment such as the Italian School).

Inevitably, those factors came back into play in the troubled path of the final design and construction site: hence, the form that had been built had to undergo heavy changes.

The perspex model and the large microbeton model disrupted by ISMES forced to change the transverse curvature, otherwise imperceptible, and to thicken the edges significantly. The difficulty of building on the ground a shape that was even difficult to draw implied increased costs and delays.

It is not said that, in history, periods of decadence have less charm than heroic ages. After the end, the School continued to generate languages. New languages. Languages that still expressed the "Italianness" of the structure, albeit with different accents from those of the golden years. They were isolated, often utopian, episodes, that, however, cast a retrospective light on the School's events and help us to discover some hidden aspects. For example, the one which arises from the transformation of the Nervi system into the Nervi style. It is a typically mannerist language: a quite rare kind in the large-scale structure sector (completely lacking in the "classic" period, if anything we may find it in some current experiments).

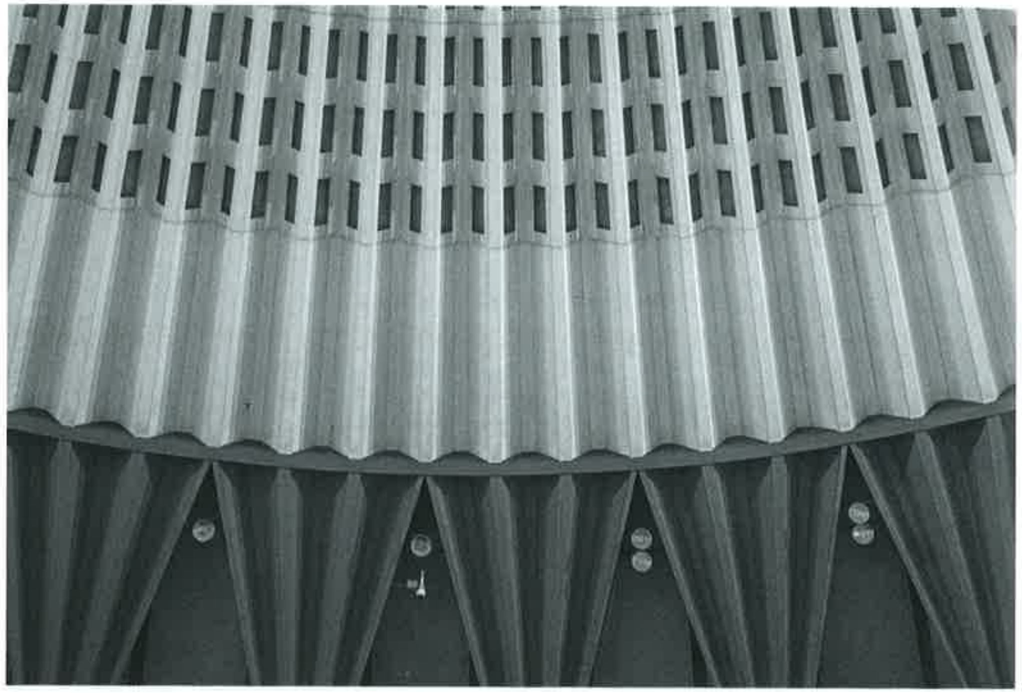

Figure 12. Sport Palace at Eur, Roma. P.L. Nervi, 1958-60. Photo: Sergio Poretti.

Another aspect is the essential language of Zorzi's mature works. The effort to sublimate simplicity of the viaduct through the drawing was an attempt to keep the School alive in the post-craft stage. But, by remaining isolated, it was revealed as a beautiful utopia. Who can recognise the well-drawn viaduct among the numerous prefabricated ones which all look the same? From a historical viewpoint, Zorzi's minimalism shedded light on yet another School's characteristics: its close affinity with the industrial

design sector. Again, another operational consequences of the humanistic character of Italian engineering.

A third "posthumous" language was expressed, not by an author, but by a single work, namely by the bridge over the Basento River. After the transformations it had suffered in the design-to-construction transition, the bridge took on a dual guise: as in an Escher's drawing, it appeared to us alternatively as a heavy shell wall – a pachyderm – or as a stretched upside-down membrane - a spider web.

As a result of such ambiguity, the structure offers us a portrait of the Italian School at the most dramatic moment of its final crisis.

Conclusions

When the School reached its maturity, during the autarchy, it was part of the great international family of modern engineering. In its later years, one thing remained for sure: Italian engineering remained perfectly orthodox.

At the same time, the story has highlighted how the Italian School gradually took on its unique identity. The structures built showed ever more clearly their distinctive features. Despite the many, different shades, a trait that they share and let them stand out in the international scene: their marked architectural value.

How was that "architectonics" of Italian engineering generated?

Avoiding the cliché of Italian creativity, our long reconstruction indicates some historical circumstances that are the basis of the School's unique prerogatives. On the one end, the Italian engineer grew in a unique cultural environment, very different from that in which, for example, the English-speaking engineer worked. In such a context, science and technology played a central role. The engineer was the hero of modernisation, a bridge builder, a model for everyone.

In Italy, throughout the 20th century, the wind blew in the opposite direction: engineering (and applied science in general) was subjected to a 'humanisation' process. Idealism and Catholicism dominated Italian culture throughout the century. The Italian engineer's positivism took on a wide range of humanistic directions. Tracing the School's development, we have met some.

We have seen, for example, a widespread historicist hint. The dogma of modernity that imposed a 'break with the past' did not take root in Italy. Italian engineers looked at ancient works with sincere admiration. Nervi's nostalgia for the prescientific era when architecture and engineering were not yet distinct was shared by everyone.

We have seen the special sensitivity for the figurative aspect. A peculiarity we have attributed to interactions with futurism. Futurism draws some shades from engineering: positivism, scientism and technologism. In return, engineering absorbs from futurism a certain visionary flavour.

Finally, we have noticed the sense of "drawing". The elective affinity with this area of the architectural culture is due primarily to the coexistence of engineers and industrial designers in the Lausanne school, and then also to an "anthropological" similarity that brings structures closer to industrial design objects than to buildings. After all, a bridge is an item of everyday use, such as table, bicycle, moka, etc.

Historicism, futurism, industrial design: different features indicate the impact of humanistic culture on the Italian engineer's traits, that also reflects the economic and productive conditions in the country.

As emerged consistently from our reconstruction, Italian engineering was to participate in completely anomalous modernisation: a gradual path with no industrial revolutions and entrepreneurial concentrations. Actually, the School operated in a country that was locked in a state of proto-industrialisation, in which the idea of progress coexisted peacefully with craftsmen's traditions. Hence, the workers' skills, low cost of labour, and low mechanisation were preserved. Thus, humanism as a result of the cultural milieu adds to the humanism of working practices, in which the engineer was fully involved. We can assume that the particular architectural value of the Italian structure is derived from this combination of humanistic factors.

That was the origin of the extreme "Italianness" of the School: a special historical significance, which explains how the structure became a symbol for the vicissitudes of the country. A real monument to the "Made in Italy".

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